S
621.434
E30tse
2001

Two Stroke Engine

Technology Overview

STATE DOCUMENTS COLLECTION

MAR 0 8 2002

MONTANA STATE LIBRARY
1515 E. 6th AVE.
HELENA, MONTANA 59620

April 30, 2001

Prepared by
John Williford
Chrysalis Technology Group, Ltd.

Prepared for
Montana Department of Environmental Quality
Helena, MT 59620

MONTANA STATE LIBRARY
3 0864 0015 3383 8

TABLE OF CONTENTS

PROJECT INTRODUCTION 3

TWO-STROKE ENGINE TECHNOLOGY OVERVIEW 4

BRIEF REVIEW OF THE TECHNOLOGY AND ITS STRENGTHS/WEAKNESSES 4

STRENGTHS OF THE TWO-STROKE ENGINE 7

DISADVANTAGES 7

COMPARISON TO COMPETING ENGINE TECHNOLOGIES 8

FOUR-STROKE PISTON ENGINES 8

THE WANKEL ENGINE 11

REVIEW OF TWO-STROKE APPLICATIONS 12

CURRENT RESEARCH THRUSTS IN TWO-STROKE ENGINE TECHNOLOGY AND TECHNOLOGY SUBSTITUTIONS 16

PATENT LITERATURE 16

TECHNICAL LITERATURE 30

ON-LINE SOURCES OF INFORMATION 30

DIRECTION OF FUTURE RESEARCH 32

TWO-STROKE ENGINE TRANSPORTATION APPLICATIONS 33

PROBLEMS WITH TRANSPORTATION APPLICATIONS 34

POTENTIAL SOLUTIONS 34

ECONOMIC DEVELOPMENT OPPORTUNITIES 40

REGULATORY AND INSTITUTIONAL ISSUES 41

CONCLUSIONS 44

APPENDICES 46

APPENDIX A - TABLE OF PATENTS EMPHASIZING FUEL INJECTION 46

APPENDIX B - BIBLIOGRAPHY OF TECHNICAL LITERATURE, EDITED COMPENDEX SEARCH BY JOHN WILLIFORD. 60

END NOTES 105

STATUS AND PROSPECTS FOR TWO-STROKE ENGINES USED IN OFF-ROAD RECREATIONAL VEHICLES

John Williford

Chrysalis Technology Group, Ltd.

April 30, 2001

PROJECT INTRODUCTION

This Phase I or baseline review of the status of two-stroke engines and competing technology has been taken up by Chrysalis Technology Group, Ltd. at the request of the National Center for Appropriate Technology (NCAT), which is in turn funded by agencies of the State of Montana for this project.

The emphasis is on larger, two-stroke, spark ignition (gasoline) engines for use in off-road vehicles. A primary focus is on snowmobiles, which have been economically important in National Parks, and on personal watercraft, which share similar, two-stroke engine technology.

The project is directed toward prospects for improvements to two-stroke engines, especially with regard to lowered emissions. Alternative technologies are also identified, but are described in less detail.

Recreational and tourist industries are important to the State of Montana, and preservation of winter season activities (snowmobiling) is accordingly of great interest.

Conflicts between environmentally concerned groups and stakeholders in continued use of recreational vehicles such as snowmobiles and personal watercraft remain unresolved.

It is our purpose to identify technical issues and developmental pathways that may help these groups resolve differences in a way that is consistent with good science and engineering.

It is a further purpose to identify, to the extent possible, commercial opportunities beyond tourism that might be developed in the State of Montana to diversify and strengthen its economic activity.

TWO-STROKE ENGINE TECHNOLOGY OVERVIEW

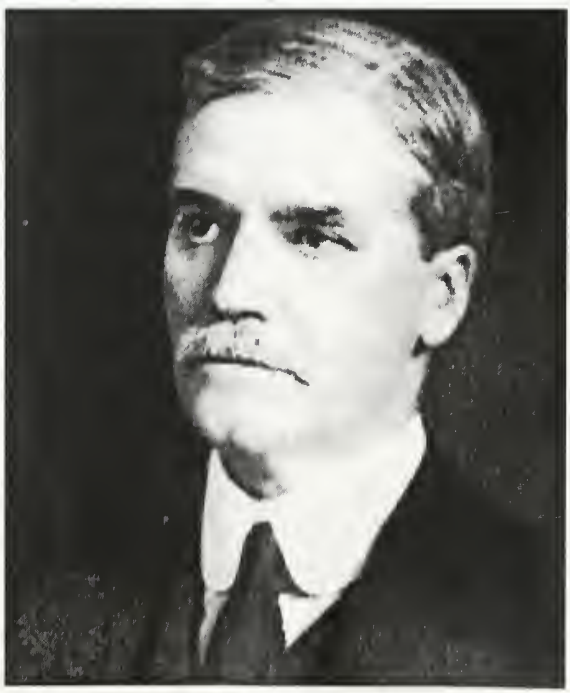
This section will provide an overview of two-stroke engine technology, under the following headings:

- Brief review of the technology and its strengths/weaknesses
- Comparison to competing engine technologies
- Review of two-stroke engine applications
- Current research thrusts in two-stroke engine technology and technology substitutions
- Direction of future research

BRIEF REVIEW OF THE TECHNOLOGY AND ITS STRENGTHS/WEAKNESSES

The two-stroke spark ignition engine is an old, and reasonably simple technology. Sometimes called the Clerk Cycle engine, the concept was patented in 1881 by Sir Dugald Clerk. In contrast to the four-stroke or Otto Cycle engine, which produces a power stroke on every fourth stroke, the two-stroke or Clerk Cycle engine provides a power stroke for every other stroke[i].

To put a human face on technology, Sir Dugald Clerk is shown in Figure 1, below.

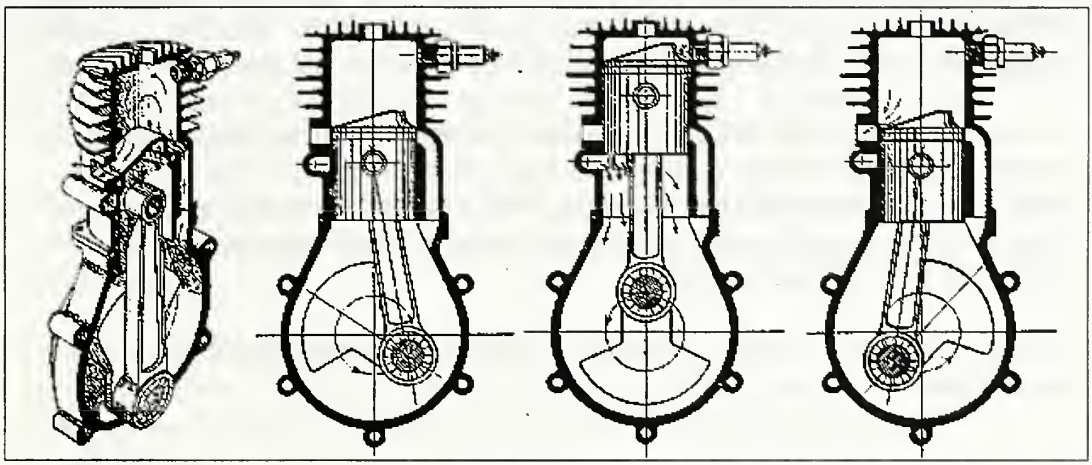


Source: Encyclopedia Britannica. http://www.britannica.com

Figure 1. Sir Dugald Clerk, Inventor of the Two-Stroke Engine.

The original Clerk two-stroke engine used a second piston as a charging pump. Ten years later (1891), Day eliminated this device and simplified the engine by using pressure from a sealed crankcase. This is the version that we see most often, and is used as a baseline in understanding the technology.

A simple description of the two-stoke engine, with illustrations, may be found at the Australian Steam and Engine site at http://www.steamengine.com.au/ic/engines/simple_engine/petrol-2.html Figure 2 and the italicized descriptions of elements of the engine cycle are from that site, with minor editing.



Source: Steam & Engine of Australia © Paul Pavlinovich used with permission.

Figure 2. Illustration of the Operation of a Simple, Two-Stroke Spark Ignition Engine.

(In the above figure, the crankshaft is rotating counterclockwise).

Figure 2 shows a cut-away diagram of a Two-Stroke, spark ignition gasoline engine. The term "two stroke" comes from the fact that the engine fires (burns fuel) on every upward stroke (travel of the piston from bottom of the cylinder to the top), thus there are two strokes for every ignition of fuel, an upward and a downward stroke. The first stroke moves from bottom to top, where compressed air and fuel ignite and begin the second stroke

where the piston is forced back downwards by the explosive force of the fuel igniting.

At the far left in Figure 2, the piston is at Bottom Dead Center (BDC), i.e., at the lowest point of travel within the cylinder). Using crankcase pressure, a mixture of air, gasoline and lubricant is forced into the cylinder, and exhaust gases are driven out.

The second image from the left in Figure 2 shows the compression of the air/fuel mixture as
the piston moves upwards, covering the air intake and exhaust ports. This happens on every upward stroke of the piston.

The third image from the left in Figure 2 shows the piston as it reaches the uppermost portion of its travel at Top Dead Center (TDC). At this point, the spark plug is fired, igniting the compressed mixture within the cylinder. At the same time, gasoline and oil vapor are being drawn into the crankcase in preparation for the next stroke.

The last illustration on the right in Figure 2 shows the downward stroke, wherein the exhaust port opens, and the cylinder is swept clean of burnt fuel by the fresh air from the inlet port. The gasoline, lubricant and air charge within the crankcase is compressed during this stroke, in preparation for the next stroke.

The cycle shown in Figure 2 is repeated for every revolution of the crankshaft.

On the Internet, there is a good site that provides an explanation and an animation of the operation of the two-stroke engine. This may be visited at:

http://library.thinkquest.org/C006011/english/sites/2_taktmotor.php3?v=2

Another site, which provides both animation and a series of diagrams, may be found at:

http://www.howstuffworks.com/first-time.htm?referer=two-stroke1.htm

Strengths of the Two-Stroke Engine

The most fundamental strength of the two-stroke engine, as compared with the four-stroke engine, is that every other stroke is a power stroke, whereas only one of four strokes is a power stroke with a four-stroke engine. This fundamental advantage provides a significant power-to-weight advantage for the two-stroke engine, as compared with four-stroke engines. This characteristic makes gasoline-powered tools such as chainsaws possible.

The design of the two-stroke engine, as compared with the four-stroke engine, is simplified by not needing a camshaft to operate intake and exhaust valves, nor the complex, poppet-type valves themselves. In the two-stroke engine, the piston itself, moving past intake and exhaust ports in the cylinder wall, acts as a kind of sleeve valve. Lubrication is provided in vaporized form with the fuel, rather than from an oil reservoir and pump system.
The decreased weight, lowered part count and simplicity of timing combine to provide an exceptionally low manufacturing cost. In addition, the relatively simple apparatus tends to be easy to maintain and to repair.

These virtues of two-stroke engines have made them ubiquitous choices in scooters used in road transportation, where they remain workhorses in Asia in particular.

Power-to-weight advantages and responsiveness of performance have kept two-stroke engines in popularity for recreational uses in racing motorcycles, personal watercraft, recreational boat engines and snowmobiles.

With regard to emission considerations, the only area of advantage for the two-stroke engine is the lower production of NO_x as compared with four-stroke engines.

Disadvantages

The disadvantages of the two-stroke engine come from the fact that exhaust gases are forced out of the cylinder in the same stroke that admits the air/fuel/lubrication charge for the next ignition and power stroke. The use of the incoming charge to help expel exhaust gases is a turbulent process, and the imperfect result has two undesirable consequences:

- The retention of a portion of the exhaust gas in cylinder, diluting the fresh charge and leading to ignition problems.
- A portion of the air/fuel/lubricant charge escapes directly to the atmosphere with the combustion products, producing poor fuel economy and releasing high levels of hydrocarbons as air pollutants. This phenomenon is known as "short circuiting".

In addition, two-stroke engines use lubricants that are mixed with the fuel, and normally produce particulate emissions as they are burned with the fuel. Thus, in addition to direct release of lubricant by short-circuiting, burned lubricant creates additional emissions.

Because of the need for exhaust expansion as part of the tuning of two-cycle engines, noise levels are intrinsically higher for two-cycle than for four-cycle engines. Adding some port variability can provide a degree of freedom in exhaust management, and modern systems show some improvements in noise levels, as compared with earlier systems.

These weaknesses are intrinsic to two-stroke engines, and may be ameliorated by various improvements, but cannot be entirely overcome with known technology. Incremental improvements carry economic costs, which affect competitiveness of the technology.

COMPARISON TO COMPETING ENGINE TECHNOLOGIES

Competing engine technologies include the conventional, piston-type four-stroke Otto engine, and a rotor engine, the Wankel. These are discussed separately in the sections below.

Four-Stroke Piston Engines

The two-cycle spark ignition engine has, as its main competitor, the older, four-stroke engine, commonly called the Otto Cycle engine. To give equal time to Nicolaus August Otto, his picture is given as Figure 3. This is taken from an excellent website explaining the history and principles of the four-stroke engine, which may be found at:

http://techni.tachemie.uni-leipzig.de/otto/otto_g0_eng.html

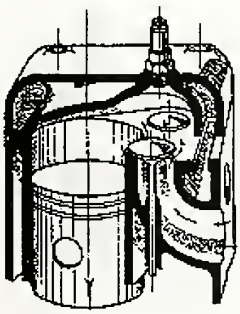
Figure 3. Nicolaus August Otto

The ITC Leipzig site also provides an animated diagram of the four-stroke engine at:

http://techni.tachemie.uni-leipzig.de/otto/index_e.html

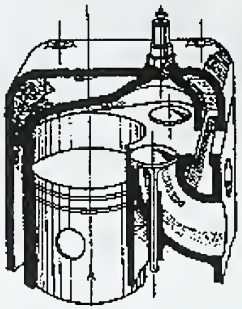
The illustrations of the four-stroke Otto cycle engine below and the associated, edited discussion in italics (*© Paul Pavlinovich used with permission*) are taken from the Australian Steam & Engine site at:

http://www.steamengine.com.au/ic/engines/simple_engine/petrol-4.html
This series shows cut-away diagrams of a Four-Stroke gasoline engine. This engine design is more complex mechanically of two and four stroke, as it requires synchronization of moving parts. The description "four stroke" comes from the fact that the engine fires (burns fuel) on every second upward stroke (travel of the piston from bottom of the cylinder to the top), thus there are four strokes for every ignition of fuel, two upward and two downward. The first stroke moves from top to bottom, where air is drawn in, the first upward stroke compresses the air and fuel is sprayed in, the air and fuel ignite and begin the third stroke where the piston is forced back downwards by the explosive force of the fuel igniting. On the fourth stroke the piston moves upwards again forcing the spent exhaust gasses out of the cylinder.



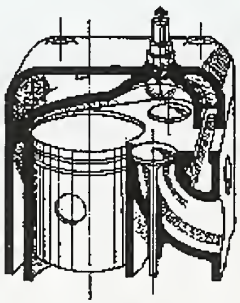
STROKE 1: SUCTION

In the diagram the piston is moving towards BDC (Bottom Dead Center - meaning it is at the lowest point of travel within the cylinder). A mixture of Air and Petrol is being drawn through the inlet valve in the top of the cylinder.



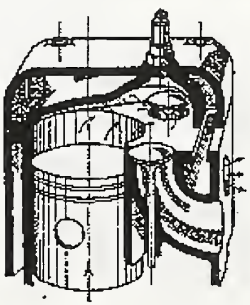
STROKE 2: COMPRESSION

The piston starts its upward movement and the air intake valve closes. The charge of fresh air and petrol is compressed to about 5% of its original volume. The act of compressing the air heats it tremendously. This happens on every second upward stroke of the piston.



STROKE 3: POWER

The spark plug fires and the combination of the spark and the high temperature of the mixture in the cylinder ignites the fuel vapour, the resulting explosion forces the piston back downward.



STROKE 4: EXHAUST

At the end of the downward stroke when the piston reaches Bottom Dead Center (BDC), the exhaust port opens, and the cylinder is swept clean of burnt fuel by the force of the piston rising in the cylinder. This entire cycle is repeated for every two revolutions of the crankshaft.

The Wankel Engine

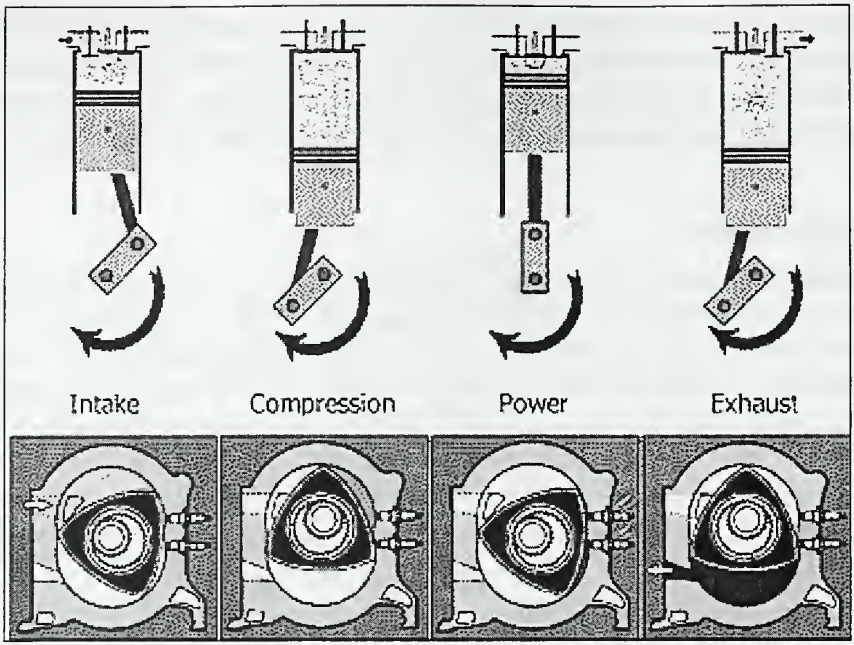
The Wankel Engine is illustrated in Figure 4, below. The figure compares the Wankel engine with the corresponding stokes of an Otto engine. The design has some intrinsic simplifications, as compared to the four-stroke piston engine, and these lead to weight reductions that make the engine competitive with two-stroke engines with respect to power-to-weight ratios[ii].

Wankel engines have been used on snowmobiles (about 15,000), motorcycles and in some aircraft applications, but much of that experience was accumulated with immature embodiments of the technology (notably with regard to sealing problems).

Problems with fuel economy and emissions have inhibited vehicular development of the Wankel technology, and expert opinion on prospects for the engine are mixed. A site which provides a somewhat dim view of prospects, along with an animation of the Wankel engine is at:

http://library.thinkquest.org/C006011/english/sites/wankel.php3?v=2

Freedom Motors, which has acquired all the Wankel intellectual property from OMC, has a more optimistic view. Their site can be reached at: http://www.freedom-motors.com



Source: Freedom Motors http://www.freedom-motors.com

Figure 4. Wankel Engine (below) compared with 4-Stroke Otto Engine.

REVIEW OF TWO-STROKE APPLICATIONS

Substantial numbers of two-stroke engines are used in chainsaws, lawn mowers and small tools. These make significant contributions to smog and air pollution in some urban localities[iii].

In the United States, emission standards for road vehicles have led to the replacement of two-stroke engines with four-stroke engines in road motorcycles and scooters. However, the two-cycle engine still dominates for scooters in Asia.

For purposes of this report, our attention is focused on recreational or off-road applications of larger, two-cycle engines. These are primarily found in personal watercraft and snowmobiles, as well as all-terrain vehicles. Conventional outboard motors for recreational boats also remain two-stroke engines.

The U.S. snowmobile market is dominated by four industry leaders, listed in Table 1, below.

Table 1
Websites for Leading
Snowmobile Manufacturers

Site	Description	URL
Arctic Cat	**Home Page**	http://www.arctic-cat.com/snowmobiles/index.asp
Polaris	**Home Page**	http://www.polarisindustries.com
Ski-Doo	**US Home Page**	http://www.ski-doo.com/home.htm?langCode=US
Yamaha Motor Corp	**Home Page**	http://www.yamahausa.com/welcome.html

The magnitude of snowmobile use is indicated by the state-by-state list of registrations for the year 2000, provided in Table 2.

Table 2
Year 2000 Snowmobile Registrations, by State

State	# Registered Snowmobiles
Alaska	19,508
Arizona	Na
California	15,888
Colorado	30,000
Idaho	40,000
Illinois	60,000
Indiana	16,877
Iowa	33,600
Maine	85,680
Massachusetts	13,000
Michigan	357,033
Minnesota	282,153
Montana	22,653
Nebraska	1,075
New Hampshire	66,000
New York	126,041
North Dakota	17,470
Ohio	22,331
Oregon	17,093
Pennsylvania	39,400
South Dakota	10,000
Utah	22,543
Vermont	32,500
Virginia	Na
Washington	32,247
Wisconsin	223,665
Wyoming	18,571
Total	1,605,328

Source: *ISMA*

Yearly sale information in terms of numbers of units and dollar value of sales is provided in Tables 3 and 4, respectively. These data are from the International Snowmobile Manufacturers Association:

http://www.snowmobile.org

Table 3
U.S. Snowmobile Sales by Numbers of Units

Year	Units
2000	136,601
1999	147,867
1998	162,826
1997	170,325
1996	168,509
1995	148,207
1994	114,057
1993	87,809
1992	81,946

Source: ISMA

Table 4
U.S. Snowmobile Sales by Dollar Value

Year	Dollars
2000	$821,000,000
1999	$882,766,000
1998	$975,147,000
1997	$1,005,790,000
1996	$905,194,000
1995	$791,277,000
1994	$556,879,000
1993	$403,921,000
1992	$356,000,000

Source: ISMA

Tables 3 and 4, taken together, show a peak sales year occurred in 1997, when about 170,000 snowmobiles were sold, for about $1 billion. This indicates an average unit price of about $5,900.

Personal watercraft have user numbers approximating those of snowmobiles, based an AP news item that describes banning of Jet Ski watercraft from all national parks. An estimated 1.2 million personal watercraft owners are in the U.S., and the average price of this product appears to be $7,000[iv].

Thus, between snowmobiles and personal watercraft, two-cycle engines are used in about three million existing vehicles. Provided that a retrofit solution could be found for these existing machines, which could be made available at a cost of $1,000, the economic impact of retrofitting all of these machines would be about $3 billion.

The personal watercraft industry appears to be slightly ahead of the snowmobile industry on provision of electronic fuel injection and other refinements to reduce hydrocarbon emissions (by 75%) and noise (by 70%)[v].

The research directions to achieve these sorts of improvements are discussed in the next section.

CURRENT RESEARCH THRUSTS IN TWO-STROKE ENGINE TECHNOLOGY AND TECHNOLOGY SUBSTITUTIONS

Several resources may be used to examine trends and topics in research on two-stroke cycle engines and substitute technologies. We have used three major information sources in collecting information for this report:

- Patent Literature
- Technical Literature
- On-Line Search Engines

These are discussed separately in the sections below.

Patent Literature

Patent literature is a useful guide to examine the range of alternative approaches which have been disclosed publicly. For this work, *Chrysalis* makes use of on-line databases. The two major resources are the U.S. Patent and Trademark site, at http://patents.uspto.gov and the Delphion site (formerly the IBM Patent Server) at http://www.delphion.com/home .

We examined the U.S. patent literature in a number of ways, drawing keywords from the technology as described in technical and background literature, and also using the US PTO Classification system to identify relevant classes and subclasses.

This type of patent work is not as focused or exhaustive as work that would be undertaken to establish novelty or potentially allowable claims, as we might do in another type of study. Our intent is to identify major trends in innovation by looking at patent activity over the past twenty years, and

through counts of multiple patents assigned to corporations, to identify industrial research centers.

Some recent U.S. Patents edited from a Boolean keyword search are given in Table 1, below. The Abstracts for these patents are given as endnotes. The terms for this search were:

[(two-stroke) (engine) (exhaust)]

The patents were sorted chronologically, and patents between 2000 and the present were edited to develop the list in Table 5. Only a few patents dealing with hand tools were excluded.

Table 5
Recent U.S. Patents on Two-Stoke Engine Technology
(2000 - 2001)

Patent Number	Title	Assignee
US6062176	Multicylinder, two-stroke, radial engine for model airplanes and the like[vi]	NONE
US6065432	Two-stroke engine operation method and internal combustion two-stroke engine[vii]	NONE (Russia)
US6079379	Pneumatically controlled compressed air assisted fuel injection system[viii]	Design & Manufacturing Solutions, Inc., Lutz, FL
US6082334	Electronically controlled fuel injection type two-stroke engine[ix]	Suzuki Motor Corporation, Shizuoka-ken, Japan
US6092494	Controlled pressure rise in two-cycle internal combustion engine having cylinder wall fuel injection[x]	Brunswick Corporation, Lake Forest, IL
US6101991	Crankcase scavenged two-stroke engines[xi]	Ricardo Consulting Engineers Limited, West Sussex, United Kingdom

US6116199	Mixture-compressing two-stroke spark ignition engine with fuel injection[xii]	Dolmar GmbH, Hamburg, Germany
US6116222	Two stroke regenerative engine[xiii]	NONE
US6119640	Internal combustion engine with slot-type gas distribution[xiv]	NONE (Russia)
US6123241	Internal combustion powered tool[xv]	Applied Tool Development Corporation, Elgin, IL
US6134885	Exhaust system tuned for performance with shared wall[xvi]	NONE
US6152102	Throttle control system for a stratified charge internal combustion engine[xvii]	Brunswick Corporation, Lake Forest, IL
US6170443	:Internal combustion engine with a single crankshaft and having opposed cylinders with opposed pistons[xviii]	Halimi; Edward Mayer, Santa Barbara, CA
US6173683	Two-stroke cycle engine[xix]	Maruyama Mfg. Co., Inc., Japan
US6188558	:Internal combustion engine with rail spark plugs and rail fuel injectors[xx]	NONE
US6196171	Loop-scavenged two-stroke internal combustion engines[xxi]	S.N.C. Melchior Technologie, Paris, France
US6197731	Smokeless two-cycle engine lubricants[xxii]	Henkel Corporation, Gulph Mills, PA

The patent search from which the recent (2000 - 2001) U.S. patents in Table 5 were drawn yielded 323 total hits. The patents were sorted by Assignees, and a manual count was done of companies holding five or more patents. The results are shown in Table 6. These companies accounted for 112 patents, or 35% of the total issued. Unassigned patents totaled 105, or 33%. The balance of the patents was distributed across a group of holders with one or only a few patents each.

Table 6
Leading Two-Stroke Patent Holders

Company	Number of Patents	First – Last
A V L Gesellschaft Fur Verbrennungskraftmaschinen Und Messtechnik M.B.H.	5	1985 – 1994
Aktiebolaget Electrolux	6	1992 – 2000
Andreas Stihl	6	1982 – 1999
Brunswick Corporation	11	1974 – 2000
General Motors Corporation	13	1975 – 1994
Honda Giken Kogyo Kabushiki Kaisha	7	1987 – 1999
Industrial Technology Research Institute	8	1975 – 1993
Institut Francais du Petrole	5	1989 – 1998
Orbital Engine Company Proprietary Limited	13	1988 – 1998
Outboard Marine Corporation	9	1989 – 1998
Toyota Jidosha Kabushiki Kaisha	16	1980 – 1993
Yamaka Hatsucloki Kabushiki Kaisha	13	1975 - 1994

Looking at the rate of patenting as an indicator of the level of activity in research, a patent count was made using the basic Boolean search used in

developing Tables 5 and 6 (i.e., keywords of "two-stroke" "engine" and "exhaust"). Patents were sorted chronologically, and manually counted, with the following results:

- 1980 - 1989 = 91 patents
- 1990 - 1999 = 174 patents
- 2000 = 18 patents

The interpretation would be that the rate of intellectual property development (at least as indicated by patents) almost doubled in the last decade of the twentieth century, as compared with the decade 1980 - 1989. The 1990 - 1999 yearly average of 17 patents appears to be sustained in 2000 (18 patents), and early results from the first quarter of 2001 indicate a continuing high rate of activity.

Other types of Boolean search were used to determine directions for emphasis on development of intellectual property. Three examples are:

- [(two-stroke) (engine) (stratified) (emissions)] = 5 patents
- [(two-stroke) (stratified)] = 19 patents
- [(two-stroke) and (fuel injection) not (diesel)] = 92 patents

Total hits from the third search, emphasizing fuel injection, were sorted by Assignee, so that activity and intellectual property inventory holdings are grouped together for each assignee. Substantial numbers of unassigned patents are sorted together, and we have no information on how these may (or may not) be licensed. All these data were used to build Table 7. Because this table is so large, we have provided it as Appendix A.

It is interesting to note that most of the emphasis in the recent patent literature is directed toward fuel injection. The U.S. Classification system has a classification that specifically deals with stratification in engines. We searched this classification, attempting to exclude work on diesels, and obtained a list of 32 hits. These were sorted by Assignee, and the data were used to build Table 8. Most of the work in this list was done following the oil embargo and price escalation of the early 1970's, and tapered off in the mid-1980's. The subsequent cycle of work in the 1990's, which continues, is driven not only by interests in fuel economy, but more importantly by emission considerations.

As a final area of patent examination, we talked with John Zabsky at KleenAir[xxiii], who identified some advances in sonic carburetors, which were made at Dresser Industries in the 1970's. A seminal patent on this topic was U.S. 3,778,038[xxiv]. Using the Delphion patent site, we looked at subsequent patents that reference U.S. 3,778,038, and sorted these by assignee to build Table 9.

This approach of using carburetor refinements, rather than fuel injection, represents an important opportunity for enhanced efficiency and hydrocarbon reduction, but does not appear to be receiving as much main line attention with the two-stroke engine as does fuel injection.

These patent searches, although not exhaustive, illustrate the major trends in the improvement of two-stroke engines from an intellectual property perspective.

Table 8
U.S. Classification 123/DIG.4 Stratification

Patent Number	Title	Date Issued	Assignee
US4236490	Internal combustion engine	12/02/1980	A. C. Engines, Inc.
US4167930	Internal combustion engine with sustained power stroke	09/18/1979	Avco Corporation
US4481911	Stratified-charge cross-flow scavenged two-stroke cycle engine	11/13/1984	Brunswick Corporation
US4481910	Stratified-charge two-stroke cycle engine	11/13/1984	Brunswick Corporation

US3658046	Mixture compressing internal combustion engine with swirl inflow and external ignition	04/25/1972	Daimler-Benz Aktiengesellschaft
US3985111	Article for defining an auxiliary compartment for an engine combustion chamber	10/12/1976	Eaton Corporation
US4018193	Vortex chamber stratified charge engine	04/19/1977	General Motors Corporation
US3987769	Jet ignition engine with valve-carried ignition chamber	10/26/1976	General Motors Corporation
US4099492	Mixture correction system during rapid acceleration in internal combustion engine with auxiliary combustion chamber	07/11/1978	Honda Giken Kogyo Kabushiki Kaisha
US4060062	Carburetor choke valve control system apparatus	11/29/1977	Honda Giken Kogyo Kabushiki Kaisha
US4026280	Choke control system for internal combustion engine	05/31/1977	Honda Giken Kogyo Kabushiki Kaisha

US3967600	Carburetor choke control device	07/06/1976	Honda Giken Kogyo Kabushiki Kaisha
US3916851	Two-cycle internal combustion engine	11/04/1975	Honda Giken Kogyo Kabushiki Kaisha
US4469054	Two-stroke internal-combustion engine	09/04/1984	Nippon Clean Engine Research Institute Co., Ltd.
US4317432	Two-cycle internal combustion engine	03/02/1982	Nippon Soken, Inc.
US3999530	Internal combustion spark ignition engine	12/28/1976	Nissan Motor Co., Ltd.
US3910248	Torch ignited reciprocatory engine and method of operating the same	10/07/1975	Nissan Motor Company Limited
US3908618	Torch-ignition reciprocating-piston type internal combustion engine	09/30/1975	Nissan Motor Company Limited
US3809039	Stratified charge spark ignition internal combustion engine with exhaust recycle	05/07/1974	Phillips Petroleum Company

US4088099	Mixture compressing, external auto-ignition four-stroke cycle internal combustion engine	05/09/1978	Porsche AG
US4126106	Mixed cycle internal combustion engine	11/21/1978	Southwest Research Institute
US3945365	Low emission combustion system for internal combustion engine using multiple spark	03/23/1976	Teledyne Industries, Inc.
US4253433	Stratified-charge two-stroke internal combustion engines	03/03/1981	The Queens University of Belfast
US3987776	Combustion chamber structure for a spark ignition engine	10/26/1976	Toyota Jidosha Kogyo Kabushiki Kaisha
US3980059	Internal combustion engine	09/14/1976	Toyota Jidosha Kogyo Kabushiki Kaisha
US3967611	Stratified-combustion type internal combustion engine with pre-combustion-chamber	07/06/1976	Toyota Jidosha Kogyo Kabushiki Kaisha
US3934562	Two-cycle engine	01/27/1976	Yamaha Hatsudoki Kabushiki Kaisha
US3923019	Two-cycle engine system	12/02/1975	Yamaha Hatsudoki

			Kabushiki Kaisha
US4574754	Stratified charge combustion system and method for gaseous fuel internal combustion engines	03/11/1986	[xxv]
US4248185	Two-cycle engine with pure air scavenging	02/03/1981	
US4106445	Reciprocating piston machine with complete combustion system	08/15/1978	
US4106439	Internal combustion engine	08/15/1978	
US3964460	Heating of intake mixture for auxiliary chamber of internal combustion engine	06/22/1976	
US3911873	Variable internal combustion engine valve operating system	10/14/1975	

Table 9
Patents that cite U.S. 3,778,038

Patent Number	Title	Assignee
US4021512	Carburetor air turbine fuel distributor	Aeronutronic Ford (now Ford Aerospace and Communications)
US4087493	Apparatus for providing a uniform combustible air-fuel mixture	Carbo-Economy, S.A.
US4231971	Flow method and device	Dresser Industries, Inc.
US4198357	Flow device and method	Dresser Industries, Inc.
US4065526	Fuel introduction device for internal combustion engine	Dresser Industries, Inc.
US4049758	Fuel introduction device for internal combustion engine	Dresser Industries, Inc.
US3987132	Fluid flow regulation	Dresser Industries, Inc.
US3965221	Fluid flow device and liquid metering	Dresser Industries, Inc.
US3949025	Variable throat venturi apparatus for mixing and modulating liquid fuel and intake air to an internal combustion engine	Dresser Industries, Inc.
US3911063	Variable throat venturi apparatus for mixing and modulating liquid fuel and intake air to an internal combustion engine	Dresser Industries, Inc.

US4021511	Fuel distributor apparatus for plug-type carburetor	Ford Aerospace & Communications
US4206158	Sonic flow carburetor with fuel distributing means	Ford Motor Company
US4056085	Engine positive crankcase ventilation valve assembly	Ford Motor Company
US4000225	Sonic flow variable area venturi carburetor	Ford Motor Company
US3931368	Fuel flow proportioning valve	Ford Motor Company
US3903215	Sonic throttle carburetor	General Motors Corporation
US4053544	Fuel induction system for internal combustion engines	J. C. Moore Research, Inc.
US4373502	Fuel control system	Miletech, Inc.
US4059415	Apparatus for reforming combustible into gaseous fuel by reaction with decomposition product of hydrogen peroxide	Nissan Motor Co., Ltd.
US4152375	Fuel supply apparatus for externally ignited combustion engines with continuous fuel addition to the suction pipe	Pierburg GmbH & Co. KG
US5302325	In-line dispersion of gas in liquid	Praxair Technology, Inc.
US3942553	Digital fluid flow control system with trim adjustment	Process Systems, Inc.
US4234522	Variable diffuser for carburetors	Regie Nationale des Usines Renault

US3931814	Cylinder-induction responsive electronic fuel feed control carburetors	Regie Nationale des Usines Renault
US3868936	Fuel injection systems	Regie Nationale des Usines Renault
US3953548	Fuel injection system	Robert Bosch GmbH
US4235375	Fuel injection valve and single point system	The Bendix Corporation
US4230273	Fuel injection valve and single point system	The Bendix Corporation
US4639340	Dissolving gas in a liquid	The BOC Group plc
US4056583	Variable venturi carburetor	Toyota Jidosha Kogyo Kabushiki Kaisha
US4867918	Gas dispersion process and system	Union Carbide Corporation
US4861352	Method of separating a gas and/or particulate matter from a liquid	Union Carbide Corporation
US4931225	Method and apparatus for dispersing a gas into a liquid	Union Carbide Industrial Gases Technology Corporation
US4215535	Method and apparatus for reducing nitrous oxide emissions from combustors	United Technologies Corporation
US6082711	Carburetor throttle valve flow optimizer	xxvi
US5942159	Carburetor throttle valve flow optimizer	
US4526729	Vortex carburetor	
US4420438	Carburetor throttle valve method and apparatus	
US4322376	Carburetor	

US4280969	Carburetor	
US4250856	Fuel-air ratio automatic control system using variable venturi structure	
US4234527	Evaporative carburetor for combustion engines	
US4189101	Stable vortex generating device	
US4187805	Fuel-air ratio controlled carburetion system	
US4139581	Carburetor	
US4109862	Sonic energy transducer	
US4070279	Eductor for dissolving gases in liquids	

Technical Literature

Chrysalis uses an on-line subscription to COMPENDEX Web for searches of technical literature. Our search in this instance has been confined to the databases covering the period of 1990 to the present time.

A master compilation of references, edited from a collection of 467 hits, is provided as Appendix B. This list of citations, which includes abstracts, will give a good overview to research that has been done on two-stroke engines. As with the collection of patents, the literature validates a concern with scavenging of exhaust gas, running with leaner mixtures, and other measures to improve efficiency, fuel economy and lower emissions.

On-Line Sources of Information

Considerable time was spent on-line, using search engines to find sites related to on-going research or developments of interest. Table 10, below, lists some of the more interesting sites, and these can be accessed from the HTML version of this report (if on-line) by clicking the URLs. Use the BACK button of the browser to return to this place in the report.

Table 10
Research Related Sites

Site	Description	URL
Argonne	Engine Materials Page (ceramics for two-cycle engines, etc.)	http://www.transportation.anl.gov/ttrdc/engine/enginematerials.html
Erickson Motors	Migrating Combustion Chamber engine	http://www.ericksonmotors.com/index.htm
Montana DEQ	Alternative Fuels (biofuels) and Snowmobile Emissions (paper)	http://www.deq.state.mt.us/ppa/p2/biofuels/biofuels.htm
National Academy of Sciences	Partnership for New Generation of Vehicles (report)	http://www.nap.edu/html/pngv5
Rotary Steam Engine	Animated graphics of simple and compound steam engines	http://www.greenhills.net/~apatter/wankel.html
Wankel Rotary Engines	Links to various sites and issues	http://www.monito.com/wankel/research.html
West Virginia Univ.	Alternative fuel and engine research	http://www.cemr.wvu.edu/~wwwatf

Table 11, below, lists some commercial sites of interest in the development or introduction of new technology. Atomized Fuel Technology is a site of special interest, as their products represent an alternative to fuel injection, and appear suited for retrofit to existing snowmobiles.

Table 11
Commercial Activity Sites

Site	Description	URL
AFT	**Atomized Fuel Technology Home Page**	http://www.aftcarbs.com
D.I.P.S. site	**Direct injection systems for two-cycle engines**	http://www.dipspower.com/index.htm
Freedom Motors	**Rotary Engines**	http://www.freedom-motors.com
Formula 500 Racing Web	**Thread on four-cycle activity by manufacturers**	http://www.f500.org/pipermail/f500/2001q1/003649.html
Orbital	**Injected marine engine**	http://www.orbeng.com.au/tech/marinpap.htm

These on-line resources have helped us understand the current status of the technical developments for two-stroke engine use in snowmobiles and personal watercraft, as well as the environmental and regulatory issues surrounding their evolution.

DIRECTION OF FUTURE RESEARCH

The climate of research on two-stoke engines remains vigorous, but we do not foresee any novel directions for work on the horizon. The Holy Grail for the two-stoke engine is to overcome problems with efficiency and emissions so that advantages of power-to-weight and torque, as compared to four-stroke engines, can be extended to automobiles. In our view (Chrysalis Technology Group, Ltd.), this is not likely to happen. However, we do see substantial further improvements that can be made economically.

The major research options are as follows:

- Improved scavenging through combinations of porting geometry and fuel delivery.
- In-cylinder enhancements of combustion through catalytic coatings.
- Application of variable exhaust tuning to enhance scavenging and level out performance over a larger range of engine rpms.
- Enhanced atomization and delivery of air/fuel mixtures for leaner burning.
- Catalytic treatment of exhaust to reduce emissions.
- Modifications of fuel formulation to improve performance.
- Substitution of lubricant formulations to reduce both HC and particulate emissions.

A major area of competition in approaches to two-cycle engine improvement will be between fuel injection and retention of carburetor fuel delivery, wherein functional characteristics in combination with cost will be issues. Sonic or atomizing carburetor designs have shown some merit, but do not appear to have the level of research attention shown for fuel injection.

It should be noted that some technologies for two-stroke engine improvement (e.g., fuel management, catalytic exhaust treatment, in-cylinder catalysis, etc.) may be applied to other types of engines as well. Improvements to conventional, four-stroke engines and to newer engine types such as Wankels create new benchmarks for performance, in a sense moving the goalposts for expectations or demands for performance. As an example, some commercial vehicles, using four-stroke engine technology, are reported to put out cleaner air from their tailpipes in some locations (e.g., Los Angeles) than the air taken in from the surrounding atmosphere.

TWO-STROKE ENGINE TRANSPORTATION APPLICATIONS

In the world at large, the preponderant use of two-stroke engines for transportation is in scooters and motorcycles. These uses in the U.S. have been largely supplanted by the use of four-cycle engine motorcycles and scooters.

Domestically, two-stroke gasoline engines are used in marine engines for recreational boating, and also for off-road recreational vehicles such as

snowmobiles. The development of recreational vehicle usage in the U.S. has been dealt with earlier in the section dealing with applications.

Although the numbers of two-cycle, off-road vehicles remain comparatively small, the uses of certain classes, such as personal watercraft and snowmobiles, bring them into view against the other users of waterways or wilderness facilities.

PROBLEMS WITH TRANSPORTATION APPLICATIONS

Problems with two-stroke engines in public settings such as national parks are seen as flowing from the high emissions and noise levels of the simple two-stroke engine. Manufacturers of personal watercraft have commercialized technologic refinements that have addressed some of these issues, but there are large inventories of existing equipment with older, two-stroke technology. As indicated earlier, based on industry statistics, there are about 3 million personal watercraft and snowmobiles registered in the United States.

The problems with two-stroke engines in these transportation applications can be significantly dealt with in new products, which provide for reduced emissions and noise. But, an additional problem is how earlier personal transportation equipment might be brought into compliance for operation in public parks. We have found comparatively little information on retrofitting technology to the older machines to deal with environmental concerns.

POTENTIAL SOLUTIONS

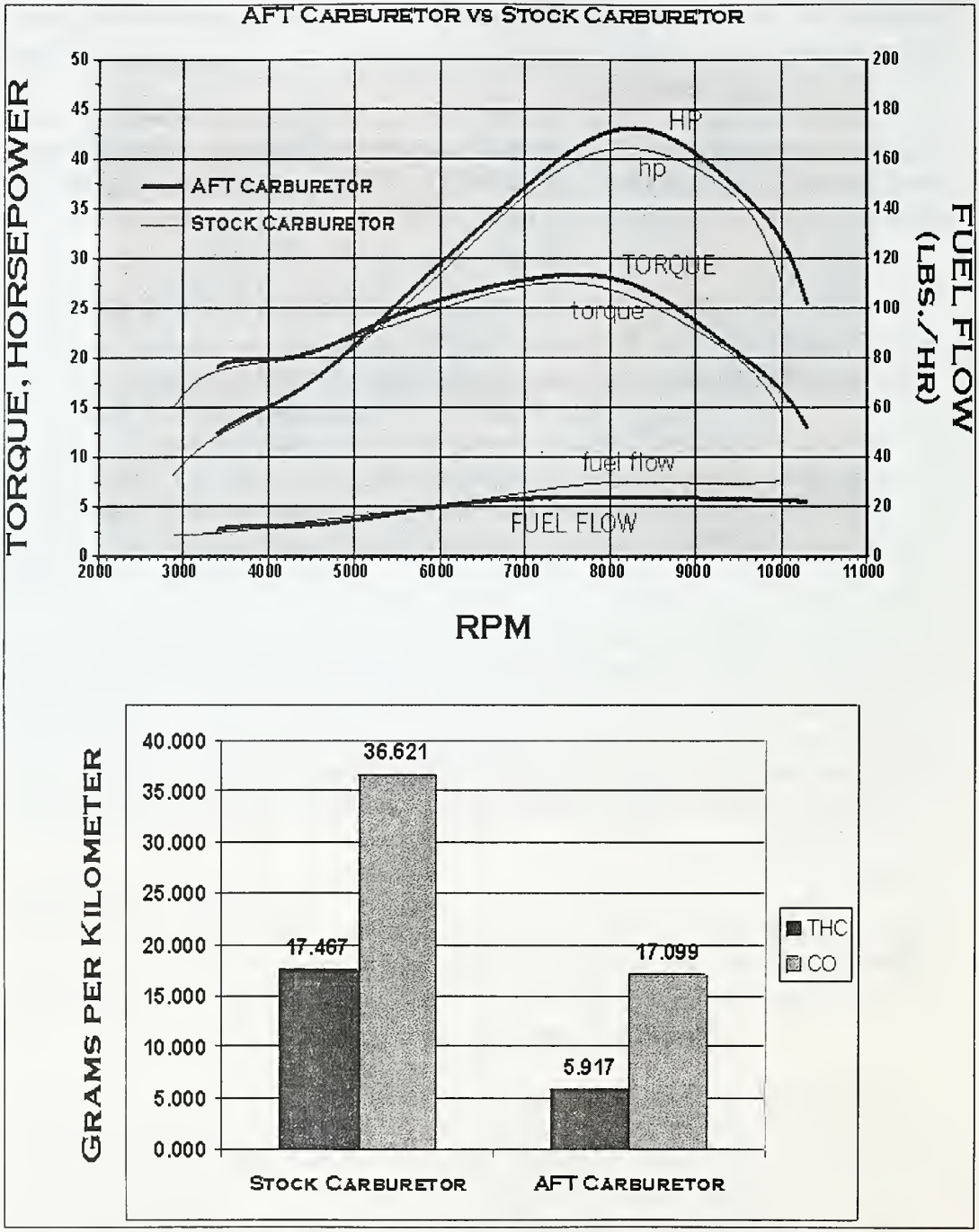
In general, directions for improving two-stroke engines have already been covered. The prospects for lowering emissions to levels 75% below earlier technology have already been demonstrated in personal watercraft, primarily by use of fuel injection and variable exhaust ports.

One of the companies we contacted has conducted tests of snowmobile engines equipped with atomizing carburetors and catalytic converters (as an alternative to electronic fuel injection systems). Although this is not yet a commercial product, the intent is to offer kits for retrofitting engines of major snowmobile manufacturers with atomizing carburetors and catalytic converters at a cost of about $750. AFT carburetor and catalyst technology was fitted to a Polaris 550 snowmobile engine, and test by an independent testing laboratory (California Environmental Engineering). The outcome, compared to baseline tests against a stock engine, showed a hydrocarbon reduction of 72.5%, and CO reduction of 82%. NO_x emissions were

increased by 7%. The website for this company, Atomized Fuel Technologies, Inc.[xxvii], may be visited at:

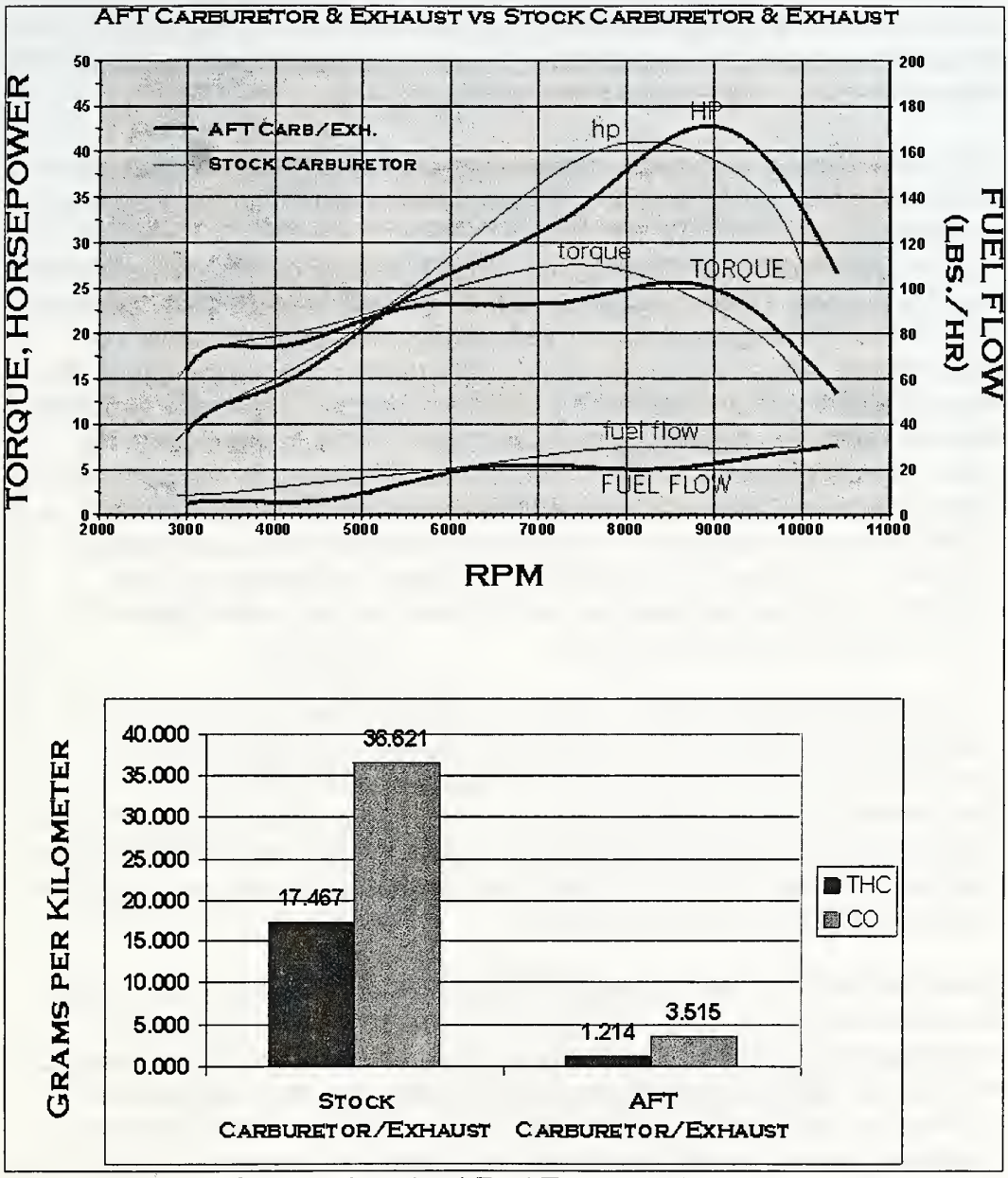
http://www.aftcarbs.com

The experience with two-stroke motorcycle engines, using AFT carburetors alone, is illustrated in Figure 5, and the experience with both carburetor and exhaust catalyst is shown in Figure 6.



Source: Atomized Fuel Technologies, Inc.

Figure 5. Comparisons of Total Hydrocarbon and CO Emissions from Stock and AFT Carburetors, Honda 250cc Two-Stroke Engine.



Source: Atomized Fuel Technologies, Inc.

Figure 6. Comparison of Stock Carburetor/Exhaust with AFT Carburetor/Exhaust, Honda 250cc Two-Stroke Engine.

Atomizing carburetors and catalytic converters for two-stroke engines are the only aftermarket solution that we have identified as a commercial objective so far. The balance of the approaches appear to emphasize the refinements to newly manufactured two-stroke equipment, substitution of four-stoke engines for two-stroke engines in new machines, or adoption of newer versions of four-stroke rotary engines.

Major snowmobile manufacturers have begun to introduce new machines powered by four-stroke engines. This appears to be the primary approach to keeping access to Yellowstone and Glacier National Parks, and the technology for meeting any imaginable requirements for emissions or noise is easily in hand with conventional, four-stroke engines. Such machines have already been placed in park settings, and the experience will be expanded in the next winter season, before restrictions are imposed. The major problem with the four-stroke solution is that the engines are roughly twice as heavy for the same power, and both throttle response and top speed characteristics of snowmobiles are compromised by the substitution. The four-cycle engine, which has substantially larger numbers of parts, is intrinsically more expensive. In its simplest embodiment, a two-stroke engine has only three moving parts - the piston, connecting rod and crankshaft. Four-stroke engines require cams, valves, valve lifters and other components to control timing.

The prior history of four-stroke engine substitution for two-stroke engines is most richly illustrated by the motorcycle industry, which has allowed economies of scale to occur with both design and manufacturing investments. These developments continue, and the availability of lighter, high performance engines (especially as used in road motorcycles) should help minimize performance compromises as these engines are substituted for two-stroke engines in snowmobiles.

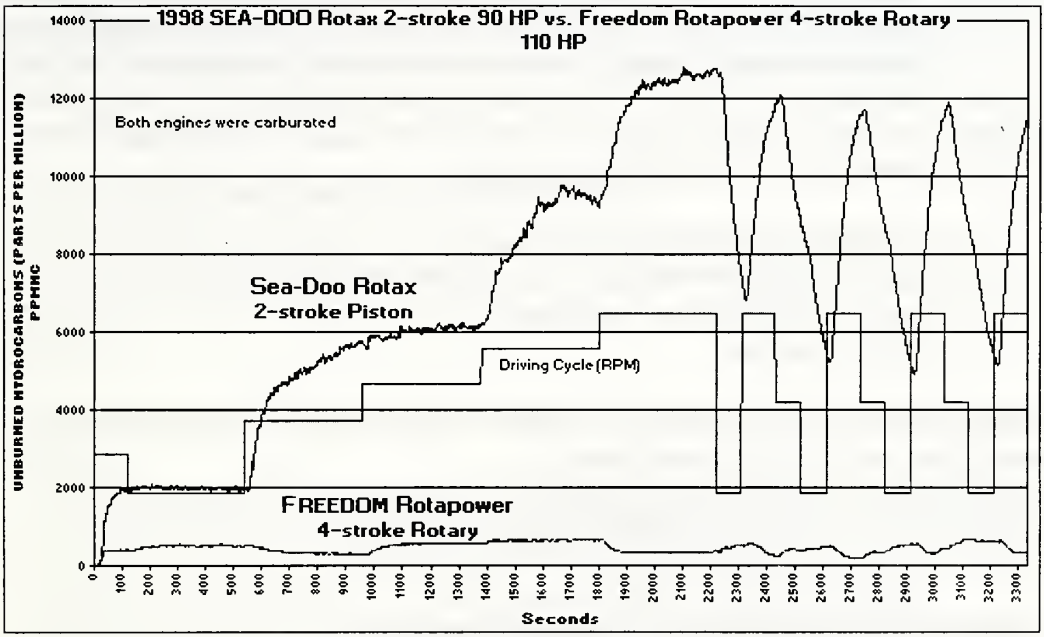
Some drawbacks in performance of four-stroke engines might technically be addressed by operating the engines at speeds where torque and efficiency are optimized, and obtaining vehicle speed control by means of a continuously variable transmission (CVT). Although we recognize that existing two-stroke snowmobiles use CVTs, we have not seen any work combining this option with four-stroke technology for purposes of optimizing performance.

As noted in the earlier discussion of competing engine technologies, the Wankel engine has had some earlier use in snowmobiles, using about 15,000 engines produced by OMC. The technology has presented several difficulties, including wear and sealing issues, and has also shown lower

fuel economy and higher emissions in automotive engines. The Outboard Marine Corporation, which had licensed Wankel patents in the U.S. and spent considerable effort on development of the technology went into bankruptcy. All of the intellectual property assets for the Wankel were acquired by Freedom Motors, which has developed additional technology for improving emission characteristics of the engine. Their website may be visited at:

http://www.freedom-motors.com .

Comparative performance characteristics of a two-stroke engine personal watercraft and a rotary engine personal watercraft are shown in Figure 7, taken from the Freedom Motors website.



Source: Freedom Motors

Figure 7. Hydrocarbon Emissions of Stock Sea-Doo Rotax 2-Stroke Piston vs. Freedom Rotapower 4-Stroke Engine.

Moving beyond these specific examples of directions for future work, Chrysalis identifies the solutions for problems of off-road recreational vehicles as being drawn from the following list:

- Substitution of four-stroke engines for two-stroke engines, (as has already occurred with road machines) to improve fuel economy and reduce emissions.
- Introduction of fuel injection to replace carburetors in new two-stroke machines (both high pressure and low pressure approaches are possible).
- Improvements in fuel atomization in two-stroke engines for leaner burning mixtures.
- Exhaust treatment systems to reduce emissions from two-stroke engines.
- Substitution of rotary four-stroke engines for two-stroke engines to maintain power-to-weight ratios of the two-stroke engine.

In the longer view, technologies such as fuel cell power systems will deserve attention for the following reasons:

- Capability to use renewable fuels
- Zero to near zero emissions to the environment
- Favorable life cycle economics
- Silent operation

Sites to review this technology include the California Air Resources Board Fact Sheet on Fuel Cell technology at: http://www.arb.ca.gov/msprog/zevprog/fcfacts.htm and the Ballard Power Systems site at http://www.ballard.com/default.asp.

ECONOMIC DEVELOPMENT OPPORTUNITIES

There is clearly a debate on the best management of access to National Parks by multiple users, particularly in winter, where the interests of mechanized users and other types of users may conflict. Although the debate continues, it appears that continued use of noisy, high-emission machinery in National Parks will not be acceptable.

It is not our place in this report to deal with the broader issues of publicly owned parklands at either federal or state level, but rather to focus on the question of how adaptations in technology may deal with concerns and preserve the interests of all parties.

In looking at the questions surrounding technical and regulatory change, we wish to identify economic development opportunities for Montana. It seems plain that restrictions on snowmobile use would impact seasonal tourist income. Looking at the national economic breakdown on snowmobiles, using data from the International Snowmobile Manufacturers Association (http://www.snowmobile.org/snowfacts.html), about 78% of the economic impact consists of the rural tourism industry. Thus, the lion's share of income from snowmobiling would lie in the support of the seasonal recreational use of snowmobiles, and in associated business through tourist services, equipment and accessory sales, and equipment service.

From the standpoint of other types of development opportunities, we believe that an attractive direction would be to work with smaller, innovative companies that are developing aftermarket products to address emissions and noise problems with the existing inventory of snowmobiles and personal watercraft. Through public/private partnering, portions of assembly or manufacturing operations for aftermarket products could be located in Montana.

REGULATORY AND INSTITUTIONAL ISSUES

The contribution of emissions from two-stroke engines to urban pollution from small engines and to other environments from larger engines used in personal watercraft, snowmobiles and other off-road vehicles has received attention.

Table 12 is a collection of websites related to environmental and emissions issues.

The climate has been marked by strong tensions between environmental groups and industry associations, with both sides using access to litigation for resolution of differences. There has also been tension between regulatory agencies at state and federal levels, and legislators. This is not a collegial setting for discourse and compromise.

Table 12
Emissions and Regulations Sites

Site	Description	URL
Blue Marble	**Clean Snowmobile 2000 results**	http://www.mdechem.com/snowmobile.htm
California Air Resources Board	**Off-Road Mobile Emissions Reduction**	http://www.arb.ca.gov/msprog/offroad/orrec/orrec.htm
EPA	**Marine Engines regulations**	http://www.epa.gov/reg3artd/vehicletran/vehicles/recreational_vehicles.htm
EPA	**Nonroad Spark Ignition Engine Emissions (links to documents)**	http://www.epa.gov/OMSWWW/equip-ld.htm
EPA	**Office of Transportation and Air Quality**	http://www.epa.gov/otaq
Pending spark engine regulations	**CFR proposals and findings**	http://legalminds.lp.findlaw.com/list/epa-air/msg02135.html

Sites in Table 12 include science-based standards and regulations generated by federal agencies for the main part, as well as the State of California.

In April 2000, a federal ruling called for the elimination of snowmobiles from national parks, including Yellowstone and Glacier. A lawsuit was filed by the International Snowmobile Manufacturers Association against this regulation, and a settlement negotiation remains underway.

Also in 2000, the National Park Service banned personal watercraft from two-thirds of the National Parks. Bluewater Network filed a federal lawsuit to extend the ban to all National Parks. The Personal Watercraft Industry Association and the American Watercraft Association both tried to intervene in this litigation, without success. A settlement agreement between Bluewater and the Department of the Interior was reached in December, 2000, agreeing that if the Department of the Interior could not prove machines do *not* harm the environment (on a case-by-case basis), the remaining 21 sites would be closed to personal watercraft by

September 15, 2002. On April 12, 2001, Federal Judge Gladys Kessler dismissed a challenge to this agreement brought by manufacturers and vendors[xxviii].

Interior Secretary Norton has recently stated that the Department will review these decisions, giving weight to the investment by industry in meeting environmental standards, and quoting figures on emission improvements from the Personal Watercraft Industry Association more or less verbatim.

With regard to snowmobile removal from National Parks, it appears that the new Administration will go along with the planned removal from Yellowstone and Glacier Parks. However, there is time for technical developments to be clarified, and for a case to revisit that decision.

Table 13 is a list of websites linking to news releases, records of Congressional Hearings, and other politically relevant matters dealing with institutional considerations.

Table 13
News and Political Items on Snowmobiles in Parks

Site	Description	URL
ABC News Item April 27, 2000	**Snowmobiles banned from National Parks**	http://abcnews.go.com/sections/travel/DailyNews/Snowmobiles000427.html
Arctic Cat Pres. Article	**Reaction to 1999 Banning of Snowmobiles in Parks**	http://www.sharetrails.org/snowmobileban/poorpoor.htm
House Small Business Committee Hearings July 13, 2000	**Impact of banning Snowmobiles on Small Business**	http://www.house.gov/smbiz/hearings/106th/2000/000713/transcript.html
House Subcommittee on Public Lands	**Testimony of Wyoming Governor May 25, 2000**	http://www.state.wy.us/governor/press_releases/2000/may_2000/wyhouse_oral.html
Manzullo Press Release	**Impact of Snowmobile Ban**	http://www.house.gov/manzullo/pr071300.htm
Montana Snowmobile Association	**Home Page**	http://www.mtsnow.org/home.shtml

Wilderness Society	**Alerts on actions and legislation**	http://www.wilderness.org/wildalert/010901.htm#rider

Table 14 provides links to manufacturers' associations dealing with snowmobiles and personal watercraft. These in turn provide links to current news items and industry viewpoints.

Table 14
Personal Watercraft and Snowmobile Manufacturers' Associations

Site	Description	URL
American Watercraft Association	**Home Page News Articles**	http://www.watercraftassociation.com/awanew/index.cfm
International Snowmobile Manufacturers Association	**Home Page with links to manufacturers**	http://www.snowmobile.org
Personal Watercraft Industry Association	**Home Page w/links to manufacturers**	http://www.pwia.org

CONCLUSIONS

Technical conclusions from this work are that the technology for improving performance and emissions from two-stroke engines appears to be moving toward acceptable levels for personal watercraft.

Replacement of two-stroke engines with four-stroke engines in some applications, notably for snowmobiles used in National Parks, may provide a quick fix to allow machines to continue to operate in these parks. The economic impact on rental operations with large numbers of machines, should replacement be necessary, could be profound.

Satisfactory solutions with retrofitted carburetor and exhaust modifications may have application to maintaining existing fleets of snowmobiles at affordable cost, while creating new economic opportunities for manufacture and distribution of such aftermarket products.

Most research on two-cycle engines will probably continue to be directed toward electronic fuel injection, and adjustable exhaust tuning. Other

technical advances in microprocessor and sensor technology will help address cost and reliability issues with some of the approaches.

In the longer view, newer internal combustion engine approaches such as the Wankel may find application to off-road vehicles, based on power-to-weight advantages as compared to four-stroke engines.

Four-stroke engines in these types of applications may be combined with continuously variable transmissions to operate in higher torque regimes to improve performance.

Gasoline engines as presently known will eventually be displaced by more efficient technologies such as fuel cell power systems, but this is unlikely to happen on a timescale consistent with keeping access to National Parks and waterways for these types of recreational vehicles.

From the standpoint of societal or institutional factors, increasing population and affluence will lead to increasing use of National Parks and Waterways, and to some mediated negotiation of the interests of differing groups of users. This debate is often more political or ideological, rather than reasoned or fact-based, so it is difficult to predict the outcome. At the present time, the clock is running on exclusion of snowmobiles and personal watercraft, but the system appears to provide for evidence that developments have been made to address health and environment issues through technologic change.

In our view, the technical resources to make these changes are available, based on the work we have reviewed in this report.

APPENDICES

Appended material includes a multi-page table of patents (Table 7) and a collection of bibliographic information. These materials have been appended to provide for improved ease in reading the main text of the report, but are an integral part of the report.

APPENDIX A - TABLE OF PATENTS EMPHASIZING FUEL INJECTION

Table 7
Patents related to Two-Stroke engines and Fuel Injection

PATENT NUMBER	ISSUE DATE	ASSIGNEE	TITLE
US05197418	03/30/1993	Andreas Stihl	Fuel injection pump for a two-stroke engine
US05197417	03/30/1993	Andreas Stihl	Fuel injection pump for a two-stroke engine in a work apparatus such as a motor-driven chain saw
US04932370	06/12/1990	Andreas Stihl	Fuel injection arrangement
US04846119	07/11/1989	Andreas Stihl	Fuel injection pump for a two-stroke engine
US04813391	03/21/1989	Andreas Stihl	Arrangement for injecting fuel for a two-stroke engine
US04700668	10/20/1987	Andreas Stihl	Method of injecting fuel for two-stroke engine and apparatus therefore

US06213370	04/10/2001	Applied Tool Development Corporation	Internal combustion powered tool
US06123241	09/26/2000	Applied Tool Development Corporation	Internal combustion powered tool
US05873508	02/23/1999	Applied Tool Development Corporation	Internal combustion powered tool
US05752643	05/19/1998	Applied Tool Development Corporation	Internal combustion powered tool
US06092494	07/25/2000	Brunswick Corporation	Controlled pressure rise in two-cycle internal combustion engine having cylinder wall fuel injection
US05924404	07/20/1999	Brunswick Corporation	Cylinder-specific spark ignition control system for direct fuel injected two-stroke engine
US05791304	08/11/1998	Brunswick Corporation	Cylinder wall fuel injection system for cross-scavenged, two-cycle combustion engine

US05762040	06/09/1998	Brunswick Corporation	Cylinder wall fuel injection system for loop-scavenged, two-cycle internal combustion engine
US04899699	02/13/1990	Chinese Petroleum Company	Low pressure injection system for injecting fuel directly into cylinder of gasoline engine
US06125824	10/03/2000	Dolmar GmbH	Method of controlling the injection process in a high-speed 2-stroke fuel injection internal combustion engine
US06116199	09/12/2000	Dolmar GmbH	Mixture-compressing two-stroke spark ignition engine with fuel injection
US06085720	07/11/2000	Dolmar GmbH	Process for controlling an injection valve in a fast-running fuel-injection two-stroke internal combustion engine and device for implementing it
US05097811	03/24/1992	Ficht GmbH	Process for

			operating a two-stroke internal combustion engine
US04984540	01/15/1991	Fuji Jukogyo Kabushiki Kaisha	Fuel injection control system for a two-cycle engine
US04941441	07/17/1990	Fuji Jukogyo Kabushiki Kaisha	Engine brake system of a two-cycle engine for a motor vehicle
US05237972	08/24/1993	General Motors Corporation	Two-stage cycle engine and combustion chamber
US04969329	11/13/1990	General Motors Corporation	Two cycle engine with exhaust emission control
US04958609	09/25/1990	General Motors Corporation	Fuel injection timing control for a crankcase scavenged two-stroke engine
US04955341	09/11/1990	General Motors Corporation	Idle control system for a crankcase scavenged two-stroke engine
US04925112	05/15/1990	General Motors Corporation	Fuel injection
US05042442	08/27/1991	Hale Fire Pump Company	Internal combustion engine
US05119792	06/09/1992	Industrial Technology Research Institute	Electromagneti c fuel injector with central air blow and

			poppet valve
US05085189	02/04/1992	Industrial Technology Research Institute	Air-assisted fuel injection applied in the two-stroke engine of flame-jet ignition type
US05080060	01/14/1992	Industrial Technology Research Institute	Prechamber combustion system with forced injection for two-stroke gasoline engine
US05027759	07/02/1991	Industrial Technology Research Institute	Fuel injection and gasifying system for two-stroke engine
US06062202	05/16/2000	Injection Research Specialists, Inc.	Two-cycle engine with electronic fuel injection
US05813374	09/29/1998	Injection Research Specialists, Inc.	Two-cycle engine with electronic fuel injection
US04967712	11/06/1990	Injection Research Specialists, Inc.	Two-cycle engine with electronic fuel injection
US04901701	02/20/1990	Injection Research Specialists, Inc.	Two-cycle engine with electronic fuel injection
US05363819	11/15/1994	Institut Francais Du Petrole	Pneumatic-injection two-stroke engine with first order balancing of the reciprocating masses
US05775274	07/07/1998	Institut Francais	Two-stroke

		du Petrole	engine with air-blast fuel mixture injection
US05419289	05/30/1995	Institut Francais du Petrole	Device for controlling the pneumatic injection of a carbureted mixture in a two-stroke internal-combustion engine and associated utilization

US04944255	07/31/1990	Institut Francais du Petrole	Two-stroke engine with pneumatic injection and flowrate restriction at the exhaust
US05749333	05/12/1998	Institute Francais du Petrole	Two-stroke internal-combustion engine depollution process and associated applications
US05404857	04/11/1995	Mercedes-Benz AG	Method for controlling a two-stroke internal-combustion engine
US06089195	07/18/2000	[xxix]	Adiabatic, two-stroke cycle engine having novel combustion chamber
US05441030	08/15/1995		Fuel injection system for two-stroke cycle engine
US05341774	08/30/1994		Self supercharged two stroked cycle and engine having migrating combustion chambers
US05154141	10/13/1992		Dual cycle engine process

US05144919	09/08/1992		Two-stroke cycle reciprocating internal combustion engine for spark ignition and crankcase scavenging
USH0000701	11/07/1989		Two cycle internal combustion engine
US04671218	06/09/1987		Two stroke engine with deflector valve
US04627390	12/09/1986		Fuel injection device for two-stroke engine
US04574754	03/11/1986		Stratified charge combustion system and method for gaseous fuel internal combustion engines
US04484543	11/27/1984		Adjustable non-throttling control apparatus for spark ignition internal combustion engines
US04399778	08/23/1983		Two cycle internal combustion engine
US04354459	10/19/1982		Non-throttling control apparatus for

			spark ignition internal combustion engines
US04205528	06/03/1980		Compression ignition controlled free piston-turbine engine
US04131090	2/26/1978 -		Two-stroke, multicylinder, spark ignition, pumpless injection internal combustion engine
US04069794	1/24/1978 -		Positive power control internal combustion engine
US06009848	1/04/2000	Mitsubishi Denki Kabushiki Kaisha	Fuel control system for cylinder injection type internal combustion engine
US05947078	09/07/1999	Mitsubishi Denki Kabushiki Kaisha	Fuel control system for cylinder injection type internal combustion engine
US04782809	11/08/1988	Motorola, Inc.	Fuel injector with electronic control circuit
US04924820	05/15/1990	Orbital Engine Company	Proprietary Limited Exhaust gas treatment for a two stroke

			engine
US04807572	02/28/1989	Orbital Engine Company Proprietary Limited	Timing of fuel injected engines
US04993394	2/19/1991	Orbital Engine Company Propriety Limited	Fuel injection internal combustion engines
US04920932	5/01/1990	Orbital Engine Company Pty. Ltd.	Relating to controlling emissions from two stroke engines
US06158409	2/12/2000	Outboard Marine Corporation	Two-stroke engine piston bowl configurations
US05970945	0/26/1999	Outboard Marine Corporation	Barrier divided combustion chamber for fuel injection two-stroke engine
US04862857	09/05/1989	Outboard Marine Corporation	Fuel injection system for multi cylinder two-stroke engine
US04779581	10/25/1988	Outboard Marine Corporation	Dual fuel injection system for two stroke internal combustion engine
US03682147	08/08/1972	Outboard Marine Corporation	Two stroke fuel inject engine with scavenged pre-combustion chamber
US04909193	03/20/1990	Performance Industries, Inc.	Exhaust control valve for fuel injected two-

			stroke cycle engines and process for using same
US04829967	05/16/1989	Piaggio & C. S.p.A.	Two-stroke internal combustion engine, with fuel injection and controlled ignition

US04020801	05/03/1977	Politechnika Karkowska	Two-stroke, multicylinder, spark ignition, pumpless injection internal combustion engine
US05609137	03/11/1997	Robert Bosch GmbH	Fuel injection apparatus for a two-stroke internal combustion engine
US05408872	04/25/1995	Sanshin Kogyo Kabushiki Kaisha	Fuel injection control device for two stroke combustion engine
US05404843	04/11/1995	Sanshin Kogyo Kabushiki Kaisha	Fuel injection device for multi cylinder two stroke engine
US04991558	02/12/1991	Siemens Automotive L.P.	Idle and off-idle operation of a two-stroke fuel-injected multi-cylinder internal combustion engine
US04706618	11/17/1987	Steyr-Daimler-Puch Aktiengesellschaft	Two stroke cycle internal combustion engine
US04807573	02/28/1989	Stihl; Andreas	Fuel injection arrangement for a two-stroke engine

US04597371	07/01/1986	Stihl; Andreas	Fuel injection apparatus for two-stroke engines
US04979480	12/25/1990	Suzuki Jidosha Kogyo Kabushiki Kaisha	Fuel injection system for multiple cylinder two-cycle engine
US06082334	07/04/2000	Suzuki Motor Corporation	Electronically controlled fuel injection type two-stroke engine
US05063886	11/12/1991	Toyota Jidosha Kabushiki Kaisha	Two-stroke engine
US05062395	11/05/1991	Toyota Jidosha Kabushiki Kaisha	Two-stroke internal combustion engine
US05016598	05/21/1991	Toyota Jidosha Kabushiki Kaisha	Fuel injection control apparatus of two-stroke engine
US04823755	04/25/1989	Toyota Jidosha Kabushiki Kaisha	Fuel injection system for an internal combustion engine
US06189495	02/20/2001	Walbro Corporation	Direct cylinder fuel injection
US06026769	02/22/2000	Walbro Corporation	Mechanical direct cylinder fuel injection
US05682845	11/04/1997	Walbro Corporation	Fuel delivery system for hand-held two-stroke cycle engines
US04995349	02/26/1991	Walbro	Stratified air

		Corporation	scavenging in two-stroke engine
US05329907	07/19/1994	Yamaha Hatsudoki Kabushiki Kaisha	Fuel injection control device for two stroke combustion engine
US05184589	02/09/1993	Yamaha Hatsudoki Kabushiki Kaisha	Fuel injection control system
US05181493	01/26/1993	Yamaha Hatsudoki Kabushiki Kaisha	Operation control device for in-cylinder injection engine
US05172666	12/22/1992	Yamaha Hatsudoki Kabushiki Kaisha	Fuel injection control system

APPENDIX B - BIBLIOGRAPHY OF TECHNICAL LITERATURE, EDITED COMPENDEX SEARCH BY JOHN WILLIFORD.

Emissions from two outboard engines operating on reformulated gasoline-containing MTBE

Author(s): Gabele, Peter A.; Pyle, Steven M.
Author Affiliation: U.S. Environmental Protection Agency
Source: Environmental Science and Technology v34 n3 Feb 1 2000 ACS Washington DC USA p 368-372 0013-936X ESTHAG
Abstract: Air and water pollutant emissions were measured from two 9.9 HP outboard engines: a two-stroke Evinrude and its four-stroke Honda counterpart. In addition to the measurement of regulated air pollutants, speciated organic pollutants and particulate matter emissions were determined. Aqueous samples were analyzed for MTBE (methyl tertbutyl ether) and BTEX (benzene, toluene, ethylbenzene, and xylene) emission rates. Compared to the four-stroke engine, the two-stroke had dramatically higher levels of toxic organic and particulate matter emissions. The organic material emitted from the two-stroke engine resembles the test gasoline due to the predominance of unburned fuel. Emission rates for PM10 (particulate matter with a diameter of 10 μm or less) are equal to those for PM2.5, implying that emitted particles are all in the respirable range. Aqueous emissions from the two-stroke are also higher: the two-stroke's BTEX and MTBE emissions are, on average, 5 and 24 times higher, respectively, and 3-10% of the MTBE fed to the engine is emitted to the water. Aqueous emission rates, expressed in brake-specific unit, tend to increase with decreasing engine load, as do the atmospheric emission rates. **English** (Author abstract) 11 Refs.

Emissions from in-use lawn mowers in Australia

Author(s): Priest, M.W.; Williams, D.J.; Bridgman, H.A.
Author Affiliation: Univ of Newcastle
Source: Atmospheric Environment v34 n4 2000 Elsevier Science Ltd Exeter Engl p 657-664 1352-2310 ATENBP
Abstract: Concern over the levels of pollutants emitted from small engines has led to recent legislation in the United States that regulates exhaust emissions from lawn and garden equipment. Particular attention has focused on the high levels of hydrocarbons emitted by these engines. The present study establishes emission factors for lawn mowers in use in Australia. The estimates were calculated on the basis of a series of controlled emission tests conducted on commonly used lawn mowers. Ten two-stroke and six four-stroke lawn-mower engines were operated under

simulated power requirements while fuel usage and gas emissions were monitored. Fuel consumption rates from the tests were compared to those ascertained under actual mowing conditions in field tests conducted on 19 two-stroke and ten four-stroke lawn mowers. Basic emission factors were established for CO, CO2, CH4, NMHC and NOx, and combined with data on machine population and annual usage collected in a survey of lawn care practices and lawn-mower usage conducted in the Newcastle area. When compared to transport sources in the Newcastle study region, lawn mowers contribute 5.2 and 11.6% of CO and NMHC emissions, respectively. **English** (Author abstract) 12 Refs.

In-use snowmobile emission survey in Yellowstone National Park
Author(s): Bishop, Gary A.; Stedman, Donald H.; Hektner, Mary; Ray, John D.
Author Affiliation: Univ of Denver
Source: Environmental Science and Technology v33 n21 Nov 1 1999 ACS Washington DC USA p 3924-3926 0013-936X ESTHAG
Abstract: Snowmobiles (sleds) have become a very popular way for visitors to explore Yellowstone National Park during its winter season with more than 60000 visits during the 1997-1998 season. In-use emissions data are very limited, and only a small number of sleds tested under controlled conditions have had their measurements reported. Snowmobiles are currently manufactured and marketed in the U.S. by four companies: Arctic Cat, Bombardier (Ski-Doo), Polaris, and Yamaha. Using the University of Denver's nondispersive infrared remote sensing equipment carbon monoxide (CO) and hydrocarbon (HC) emission measurements were collected on 1210 sleds at the West Yellowstone, MT park entrance during 4 days in February 1998. Mean emissions for the measurements were 5.56 ± 0.07% CO and 2.58 ± 0.02% HC (as propane). Using a carbon to hydrogen molar ratio of 1:2 for the fuel, the emissions are 460 ± 6 g CO and 331 ± 2 g HC per kilogram of fuel consumed. This is in large part because snowmobiles utilize conventional two-stroke engine designs, which cannot avoid extensive blowzy (the exhaust port and intake port being open at the same time) of the unburned fuel, oil, and air mixture which is also poorly regulated by simple carburetors. **English** (Author abstract) 12 Refs.

Palm oil and mineral oil based lubricants - their tribological and emission performance
Author(s): Masjuki, H.H.; Maleque, M.A.; Kubo, A.; Nonaka, T.
Author Affiliation: Univ of Malaya

Source: Tribology International v32 n6 1999 Elsevier Science Ltd Exeter Engl p 305-314 0301-679X TRBIBK
Abstract: A comparative study of wear, friction, viscosity, lubricant degradation and exhaust emissions was carried out on a palm oil and a mineral oil-based commercial lubricating oil. The wear and friction test was at first conducted using a reciprocating universal wear machine followed by a two-stroke gasoline Yamaha portable generator set, ET 950. The test conditions for the bench test were: pressure, 3.0 MPa; sliding speed, 0.20 m s-1; sliding stroke, 80 mm; room temperature, congruent 25 °C. The test conditions for the actual engine were: constant load, 0.4 kW for wear of the piston ring but various loads for exhaust emissions and constant speed, 2800 rpm. Analysis of post bench test lubricating oils was performed using ISL viscometer, TAN/TBN analyzer and FT-IR spectroscopy to investigate viscosity, TAN value and the oxidation level, respectively. Exhaust emission analysis was also performed using a BOSCH exhaust gas analyzer. Experimental results demonstrated that the palm oil based lubricating oil exhibited better performance in terms of wears, and that the mineral oil based lubricating oil exhibited better performance in terms of friction. However, the palm oil based lubricant was the more effective in reducing the emission levels of CO and hydrocarbon. **English** (Author abstract) 26 Refs.

Testing the two stroke engine using mixtures of gasoline-ethanol
Author(s): Arapatsakos, C.I.; Sparis, P.D.
Author Affiliation: Democritus Univ of Thrace
Source: Heat and Technology v 16 n 2 1998 Edizioni E.T.S. p 57-61 0392-8764 HETEEE
Abstract: A series of experiments were carried out to examine the behavior of a two-stroke engine when mixtures of gasoline alcohol are used. In the first series of tests, 120 tests were made using different gasoline-alcohol mixtures (of 95 alcoholic degrees). The second series of experiments dealt with the registration of the generator's output voltage. The third series of experiments examined fuel consumption. Results of these tests were quantified through comparison with those obtained for the four-stroke engine. **English** 61 Refs.

Database technology for visualized numerical calculation of flow for two-stroke engine
Author(s): Jiang, Yankun; Zang, Cheng; Chen, Guohua; Ma, Yuanhao
Author Affiliation: HUST
Source: Huazhong Ligong Daxue Xuebao/Journal Huazhong (Central China) University of Science and Technology v26 n11 Nov 1998 p 98-100 1000-8616 HLDXE6

Abstract: The paper deals with the database technology for visualized numerical calculation of flows in exhaust channels, transfer passages, ports and cylinder in two-stroke engine. A design method of object-oriented and data-base-structured models is put forward using efficient data structure and restrained management mechanism. Taking visualized numerical calculation of flow in 1E52FM two-stroke engine as an example, a database management system is developed. **Chinese** (Author abstract)

Operation of a small bore two-stroke linear engine
Author(s): Clark, Nigel; Nandkumar, Subhash; Atkinson, Christopher; Atkinson, Richard; McDaniel, Thomas; Petreanu, Sorin; Famouri, Parviz; Cawthorne, William
Author Affiliation: West Virginia Univ
Source: American Society of Mechanical Engineers, Internal Combustion Engine Division (Publication) ICE New Developments in Engine Design and Combustion Proceedings of the 1998 Fall Technical Conference of the ASME Internal Combustion Engine Division. Part 1 (of 3) Sep 27-30 1998 v 31 n 1 1998 Clymer, NY, USA, Sponsored by: ASME ASME Fairfield NJ USA p 33-42 AMEIEW
Abstract: A linear, crankless, internal combustion engine prototype has been developed for electrical power generation in combination with linear alternator. The operation of this engine is distinct from that of a conventional slider-crank mechanism engine, in so far as the motion of the two opposed pistons is not externally constrained. The two-stroke engine prototype, with a bore of 36.5 mm and a maximum stroke of 50 mm, operating in a gasoline-fueled spark-ignited mode, was tested successfully and found to produce approximately 316 W of electrical output power. **English** 2 Refs.

Developing a Taipei motorcycle driving cycle for emissions and fuel economy
Author(s): Tzeng, G. -H.; Chen, J.-J.
Author Affiliation: Natl Chiao Tung Univ
Source: Transportation Research, Part D: Transport and Environment v 3 n 1 Jan 1998 Elsevier Sci Ltd Exeter Engl p 19-27 1361-9209 TRDTFX
Abstract: The purposes of this study are to develop a representative driving cycle for motorcycles in metropolitan Taipei and to ascertain the emissions and fuel economy of the cycle. We collected extensive driving cycle data and proposed a methodology to develop a Taipei motorcycle driving cycle (TMDC). The characteristics of TMDC are high average acceleration and deceleration, high acceleration-deceleration changes and low average travel speed. Forty-five motorcycles were tested in a laboratory by using the ECE-40 and TMDC test procedure. The emissions

of motorcycles tested by TMDC are higher than ECE, whether they are two-stroke or four-stroke engines. Furthermore, the CO and HC emissions of two-stroke engine motorcycles are higher than four-stroke engine motorcycles, and the NOx emission of two-stroke engine motorcycles are lower than four-stroke engine motorcycles, whether they are tested by TMDC or ECE. The fuel economy of two-stroke engine motorcycles tested by TMDC is lower than ECE, but the fuel economy of four-stroke engine motorcycles tested by TMDC is higher than ECE. A linear regression of TMDC in terms of ECE emissions shows them to be highly correlated, as is fuel economy. **English** (Author abstract) 16 Refs.

Research investigation to identify the key players in the two-stroke engine industry
Author(s): Wahla, N.; Tither, D.; Naude, P.
Author Affiliation: Manchester Metropolitan Univ
Source: Technovation v 18 n 2 Feb 1998 Elsevier Sci Ltd Exeter Engl p 133-140 0166-4972 TNVTDP
Abstract: Engines, which produce power by the two-stroke combustion principle, are manufactured in considerable quantities in major industrial centres throughout the world. This paper describes part of a research investigation examining the two-stroke engine industry and the markets into which these products are sold. The publication brings together commercial and technical information, which is intended to contribute towards a better understanding of a sector of manufacturing engineering, which is part of the supply chain for the transportation and power generation industry. The paper focuses on the key players in the two-stroke combustion engine industry, from both the research and development and production points of view, and identifies the geographical location of individual sites. The overall aim of the research investigation is to be able to build a mix of expertise, including technical, commercial and marketing knowledge, related to two-stroke engines, which is valuable to those who are interested in powered transport methods. The results presented include some basic statistics of the number and spread of the key players and active sites whilst beginning to develop an understanding of the drawbacks and advantages and complementary specialisms which make up the two-stroke engine technology. **English** (Author abstract) 25 Refs.

Numerical model of a high performance two-stroke engine
Author(s): van Leersum, J.
Author Affiliation: Ian Williams Tuning
Source: Applied Numerical Mathematics v 27 n 1 May 1998 Elsevier Sci B.V. Amsterdam Netherlands p 83-108 0168-9274 ANMAEL

Abstract: A numerical model of the main processes occurring in a two-stroke internal combustion engine is described. This model does not have many of the restrictions of previous models in the literature. Particular attention is given to modelling the duct flows using a flux conservative Lax-Wendroff type algorithm modified by the use of flux splitting and flux limiters. This makes the model well able to cope with very high specific power output engines. Numerical, convergence, and flux conservation properties of the model are illustrated and engine performances predicted by it are shown to compare well with experimental data from a high performance 125 cc engine and a medium performance 100 cc engine.
English (Author abstract) 25 Refs.

Modeling and development of a linear engine
Author(s): Clark, Nigel N.; McDaniel, Thomas I.; Atkinson, Richard J.; Nandkumar, Subhash; Atkinson, Christopher M.; Petreanu, Sorin; Tennant, Christopher J.; Famouri, Parviz
Author Affiliation: West Virginia Univ
Source: American Society of Mechanical Engineers, Internal Combustion Engine Division (Publication) ICE New Developments in Engine Design, Aspiration, and Lubrication Proceedings of the 1998 Spring Technical Conference of the ASME Internal Combustion Engine Division. Part 2 (of 3) Apr 26-29 1998 v 30 n 2 1998 Fort Lauderdale, FL., USA, Sponsored by: ASME ASME Fairfield NJ USA p 49-57 Paper: 98-ICE-95 AMEIEW
Abstract: A linear engine, sans crankshaft, consisting of two opposed pistons linked by a solid connecting rod, has been designed as the potential platform for an electrical generator system with low mechanical losses. The design differs significantly from that of free-piston gas generator engines that received attention several decades ago. Idealized modeling of a two-stroke version, assuming Otto cycle behavior, has yielded a closed from solution for piston motion (in velocity-position space) assuming a frictional load, while a numerical zero dimensional model has been used to yield more realistic engine behavior under an external load. The linear engine enjoys an additional degree of freedom over conventional engines in that the piston motion is not mechanically defined, but is free to respond to changes in engine fueling and load. Sensitivity of the reciprocating frequency of the engine to stroke, bore, indicated mean effective pressure (imep), and reciprocating mass have been quantified. Concurrently, an experimental benchtop linear engine has been constructed and operated in a gasoline-fueled spark-ignited mode. The bore of this engine was 36.5 mm (1.4335 in.) and the maximum possible stroke, at the point where the pistons would contact the head, was 50 mm (2 in.). The engine was instrumented to provide piston position and in-cylinder pressure in real-time. Ignition timing and port fuel injection

pulsewidth were managed by a controller, developed in-house. The engine has been operated without external load, and displays a natural frequency of 1500 cycles per minute. Piston motion was not perfectly sinusoidal, and analysis of pressure-volume diagrams indicates that adverse work was required to slow the piston near the end of the compression stroke, because early ignition proved essential for smooth operation without load. Pressure-volume diagrams were unusual under light load, but were close to those expected from a slider-crank engine at heavy load. Development of a linear alternator is being conducted in parallel to this work, with a view to combining the engine and alternator to produce a high specific power density auxiliary power unit for mobile electrical power generation. **English** (Author abstract) 12 Refs.

Biodegradable lubricants
Author(s): Portlock, Mike
Author Affiliation: Shell Int Petroleum Co Ltd
Source: Paper Age v114 n6 Jun 1998 Global Publ Hanover MA USA p 42 0031-1081 002984
Abstract: Base oils have a low acute water toxicity, while the rate at which they decompose varies. The chain saw oil as well as hydraulic oils and two-stroke oils can not be collected and must be broken down as quickly as possible. Environmentally acceptable oils are ideal for total loss lubrication. As the world's largest oil company, Shell plays a key role in reducing the environmental impact of lubricants. **English**

Proceedings of the 1998 SAE International Spring Fuels & Lubricants Meeting & Exposition
Author(s):
Author Affiliation:
Source: SAE Special Publications State of Alternative Fuel Technologies Proceedings of the 1998 SAE International Spring Fuels & Lubricants Meeting & Exposition May 4-6 1998 v 1365 May 1998 Dearborn, MI., USA, SAE Warrendale PA USA 164p SAESA2
Abstract: The proceedings contains 15 papers. Topics discussed include duel fuel systems, fuel permeation performance, gas emissions, fuel pressure control, fuel analysis, computer simulation and fuel effects. **English**

Atmospheric pollution from motorcycles and controlling strategy in cities
Author(s): Xie, Shiwen
Author Affiliation: Tianjin Univ

Source: Zhongguo Huanjing Kexue/China Environmental Science v17 n6 Dec 1997 p 517-521 1000-6923 ZHKEEI
Abstract: The seriousness of emission from motorcycles on atmospheric pollution in cities, especially ones in China, has been expounded in this paper; the specialty of emission from motorcycles and the differences between the advanced emission regulations of foreign countries and those of China, are also been done; of all emission control strategies for motorcycles, the test results of low smoke two stroke oils are specially introduced. It's proposed that using low smoke oils is a critical measure of reduction emission from motorcycles. **English**

Effect of K2O on a Pd-containing catalytic converter for removing CO and HC emissions from a two-stroke motorcycle
Author(s): Lee, Chiou-Hwang; Chen, Yu-Wen
Author Affiliation: Natl Central Univ
Source: Industrial & Engineering Chemistry Research v 37 n 4 Apr 1998 ACS Washington DC USA p 1260-1266 0888-5885 IECRED
Abstract: Noble metals (Pt, Pd, and Rh) supported on Al2O3, K2O/Al2O3, CeO2/Al2O3, and K2O/CeO2/Al2O3 were prepared and characterized with respect to surface area, pore volume, and temperature-programmed desorption of CO2. The effects of K2O on the noble-metal catalysts for carbon monoxide and hydrocarbon oxidation were investigated. The reactions were carried out under the stoichiometric and oxygen-deficient conditions. Under the stoichiometric point, the Pd-containing catalysts exhibit higher activity than the Pt-containing catalysts for both CO and C3H6 oxidation. Moreover, Pd/K2O/CeO2/Al2O3 is the most active catalyst among the powder catalysts in this study. Under the oxygen-deficient conditions and in the presence of water, the CO conversions on Pd/Al2O3 and Pd/CeO2/Al2O3 are significantly lower than those on Pt/Al2O3 and Pt/CeO2/Al2O3, respectively. In contrast, the Pd-containing catalysts exhibit higher C3H6 conversion than the Pt-containing catalysts. However, the CO conversions on the Pd-containing catalysts can be promoted by the addition of K2O. On the other hand, the test results of the monolithic catalysts revealed that the CO conversion on PdRh/K2O/Al2O3-CeO2 is quite close to that on PtRh/Al2O3-CeO2 under the simulative gases and the ECE-40 mode driving cycle test. PtRh/Al2O3-CeO2 is the typical composition of catalytic converters for two-stroke motorcycles. It infers that PdRh/K2O/Al2O3-CeO2 is a promising catalytic converter for a two-stroke motorcycle. **English** (Author abstract) 19 Refs.

Emission control technologies for 50 and 125 cc motorcycles in Taiwan

Author(s): Wu, Hsiao-Chung; Yang, Sze-Ming; Wang, Aaron; Kao, Hsin-Chung
Author Affiliation: Natl Central Univ
Source: SAE Special Publications Advanced Converter Concepts for Emission Control Proceedings of the 1998 SAE International Congress & Exposition Feb 23-26 1998 v 1352 Feb 1998 Detroit, MI., USA, SAE Warrendale PA USA p 137-147 Paper: 980938 SAESA2
Abstract: A number of emission control strategies are used for measuring Pt/Rh and Pd-only catalysts that were installed in a 50 and 125 cc motorcycle in Taiwan. It is shown that the position of the induction of the secondary air is essential to achieve the most favorable flow rate of the secondary air for a 50 cc motorcycle. Moreover, the removal potential of the catalytic converters for carbon monoxide and hydrocarbon emission can be enhanced by introducing secondary air. **English** 9 Refs.

Fluid dynamic modeling of gasoline direct injection for compact combustion chambers
Author(s): Stan, C.; Eichert, H.; Martorano, L.; Franco, A.
Author Affiliation: West Saxon Inst of Zwickau
Source: SAE Special Publications Two-Stroke Engines and Emissions Proceedings of the 1998 SAE International Congress & Exposition Feb 23-26 1998 v 1327 Feb 1998 Detroit, MI, , USA, SAE Warrendale PA USA p 1-10 Paper : 980755 SAESA2
Abstract: Fluid dynamic process analysis was carried out to find a direct injection (DI) system that can achieve optimum conditions for mixture formation as a controlled spray distribution on the air, without impact points with the wall of the combustion chamber. The analysis consisted of process simulation and fuel jet optimization. Several injector forms were analyzed for different sequences of time/spray cross-sections in the combustion chamber. Results from both procedures were compared. The comparison confirm the efficiency of the combined method. **English** 12 Refs.

Electronic direct fuel injection system applied to an 1100cc two-stroke personal watercraft engine
Author(s): Johnson, Daren E.; Wong, Hoi-Ching
Author Affiliation: BKM, Inc
Source: SAE Special Publications Two-Stroke Engines and Emissions Proceedings of the 1998 SAE International Congress & Exposition Feb 23-26 1998 v 1327 Feb 1998 Detroit, MI., USA, SAE Warrendale PA USA p 11-23 Paper: 980756 SAESA2
Abstract: An electronic direct fuel injection (EDFI) system has been applied to a 1100cc two-stroke PWC engine. This effort proved to be very successful. In particular, it demonstrated the ability to meet the EPA

regulated spark ignited marine engine HC + NOx emission standard for the model year 2006. The system showed a 76.3% reduction in weighted mass hydrocarbon emissions. **English** 12 Refs.

Low pressure pneumatic direct injection two-stroke engine by activated radical combustion concept
Author(s): Ishibashi, Yoichi; Asai, Masahiro
Author Affiliation: HONDA R&D Co., Ltd
Source: SAE Special Publications Two-Stroke Engines and Emissions Proceedings of the 1998 SAE International Congress & Exposition Feb 23-26 1998 v 1327 Feb 1998 Detroit, MI., USA, SAE Warrendale PA USA p 25-32 Paper: 980757 SAESA2
Abstract: The concept of the stratified scavenging homogeneous charge engine applying Activated Radical combustion is proposed as a solution for the environmental conscious power units. This concept has been proven using an experimental motorcycle engine installed with a low pressure pneumatic direct injection system and an exhaust valve. Results from the LA4 emission evaluation test show that hydrocarbon emission drastically decreased close to the engine's four-stroke level. **English** 10 Refs.

Individual-cycle measurements of exhaust-hydrocarbon mass from a direct-injection two-stroke engine
Author(s): Fansler, Todd D.; French, Donald T.; Drake, Michael C.
Author Affiliation: General Motors Global Research and Development Operations
Source: SAE Special Publications Two-Stroke Engines and Emissions Proceedings of the 1998 SAE International Congress & Exposition Feb 23-26 1998 v 1327 Feb 1998 Detroit, MI., USA, SAE Warrendale PA USA p 33-53 Paper: 980758 SAESA2
Abstract: Individual-cycle exhaust-hydrocarbon measurements were performed on a direct-injection two-stroke-cycle engine. Time-resolved hydrocarbon (HC) concentration data were obtained using a fast flame-ionization detector. The resulting data were converted to individual-cycle exhaust mass flow. Two types of air-assist fuel injectors were evaluated using simultaneously acquired individual-cycle heat-release data, exhaust-HC mass data, and in-cylinder spray/combustion visualization. Results of these study were used in conjunction with previous imaging and heat-release studies to clarify the principal mechanisms leading to unburned HCs from this two-stroke engine. **English** 38 Refs.

Twenty years of Piaggio direct injection research to mass produced solution for small 2T SI engines
Author(s): Nuti, Marco; Pardini, Roberto

Author Affiliation: PIAGGIO V.E. S.p.A.
Source: SAE Special Publications Two-Stroke Engines and Emissions Proceedings of the 1998 SAE International Congress & Exposition Feb 23-26 1998 v 1327 Feb 1998 Detroit, MI., USA, SAE Warrendale PA USA p 65-78 Paper: 980760 SAESA2
Abstract: The 'phylogeny' of the Hi-Tech 2T SI engine in Piaggio started on the early 70s. Several solutions to this problem have been introduced for the past twenty years. To determine the extent of research activities in this area, an analysis has been conducted. Through this analysis, the ultimate possibilities of the 2T SI engine have been clarified. **English** 14 Refs.

Development of a low emission two-stroke cycle engine
Author(s): Sawada, Toshiharu; Wada, Minoru; Noguchi, Masanori; Kobayashi, Buhei
Author Affiliation: KOMATSU ZENOAH Co
Source: SAE Special Publications Two-Stroke Engines and Emissions Proceedings of the 1998 SAE International Congress & Exposition Feb 23-26 1998 v 1327 Feb 1998 Detroit, MI., USA, SAE Warrendale PA USA p 79-89 Paper: 980761 SAESA2
Abstract: The possibility of using stratified scavenging and lean combustion as alternative technologies for reducing THC and CO emissions was confirmed. Two different types of engines were used. One is a prototype two-stroke cycle engine with leaner combustion technology and air-head stratified scavenging, the other one is current two-stroke cycle engine with Schnurle scavenging. THC was measured on a wet basis while CO and CO2 were measured on dry basis. The prototype engine with Air-head stratified scavenging and leaner combustion reduced specific THC output to 1/5 compared to current Schnurle scavenging engine. This suggests that the engine can conform to CARB 1999 or tier 2 emission standards regarding THC, CO and NOx emission without sacrificing mechanical simplicity and light weight. **English** 5 Refs.

Two-stroke cycle engine, proscribe or prosper?
Author(s): Blair, G.P.
Author Affiliation: Queen's Univ of Belfast
Source: SAE Technical Paper Series Future Transportation Technology Conference and Exposition Aug 5-7 1991 1991 Publ by SAE Warrendale PA USA p 1-22 Paper: 911685 0148-7191 STPSDN
Abstract: This Address is concerned with the work carried out by an engineering academic at The Queen's University of Belfast over the last 26 years. It describes the motivation which impelled the author towards a career in mechanical engineering and into a specialist field from which he

has never strayed. It describes research and development into the design of the two-stroke cycle engine, which today is identified as a potential candidate for automobile powerplant production within the decade. At the same time the Address illustrates that much of this research and development, including the design, manufacture, build, test, and development of prototype automotive engines, has been heavily contributed to by both undergraduate and postgraduate students as part of their education and training at the university. It is contended that this approach is a vital component of a relevant university education and training for student and academic alike. **English** (Author abstract) 53 Refs.

IAPAC compressed air assisted fuel injection for high efficiency low emissions marine outboard two-stroke engines

Author(s): Monnier, Gaetan; Duret, Pierre

Author Affiliation: Inst Francais du Petrole

Source: SAE Technical Paper Series International Off-Highway and Powerplant Congress and Exposition Sep 9-12 1991 1991 Publ by SAE Warrendale PA USA p 123-135 Paper: 911849 0148-7191 STPSDN

Abstract: The implementation of the IFP-developed Compressed Air Assisted Fuel Injection process (named IAPAC) on a two-stroke engine allows the introduction of the fuel separately from the scavenging air in order to minimize fuel short-circuiting. The IAPAC process does not require an external air pump since the compressed air used to atomize the fuel is supplied, at no expense, by the crankcase. The premixed charge is delivered directly into the cylinder with a high spray quality and its stratification, for optimized combustion, is controlled by a valve. This process, therefore, provides the advantages of the direct injection but uses conventional low-pressure automotive type injection technology with commercially available gasoline injectors. In earlier work, we showed how the qualities of light weight, compactness, high specific power, high efficiency and low emissions make this concept particularly well adapted for future automotive applications. Marine engine exhaust emissions from most conventional 2-stroke engines are excessive, and future legislation will no doubt take this fact into account. In this paper, we show how IAPAC technology provides an interesting solution to significantly reduce the pollutant emissions and improve the fuel economy of 2-stroke outboard engines. A 3-cylinder 1,2 L marine outboard IAPAC 2-Stroke engine has been developed and extensively tested. The results obtained point out that, with maintained quality of compactness and power output, this new engine gives fuel consumption reductions of more than 25% and unburned hydrocarbon emission reductions of 70 to 90%. Pollutant emissions are evaluated according to the ICOMIA procedure and the results clearly show how the IAPAC system is well adapted to take optimum advantage of the

two-stroke cycle principle in marine outboard engines applications. **English** (Author abstract) 18 Refs.

Effective energy utilization and emission reduction of the exhaust gas in a two-stroke cycle engine
Author(s): Sato, Kazuo; Ukawa, Haruo; Nakano, Masamitsu
Author Affiliation: Shibaura Inst of Technology
Source: SAE Technical Paper Series International Off-Highway and Powerplant Congress and Exposition Sep 9-12 1991 1991 Publ by SAE Warrendale PA USA p 111-122 Paper: 911848 0148-7191 STPSDN
Abstract: This paper deals with a successful attempt to employ the exhaust gases of a two-stoke cycle gasoline engine as an energy source to operate an after burner and a Stirling engine, and to clean the exhaust gases by a catalyzer. By means of a rotary valve and the exhaust pipe sections, the exhaust gases could separated into a high concentration of fresh gas and a high concentration of combustion gas. The former gas was burned by a burner, and then used to heat a Stirling engine. The latter gas was disposed of by an oxidation catalyzer. The investigation revealed the enthalpy and exergy flows of a two-stroke cycle gasoline engine, a burner, a catalyzer and a Stirling engine, and then the emission gases (HC, CO, NO) were disposed of by the burner and catalyzer. The investigative analysis shows a method of successfully transferring the energy available in the exhaust gases for the combustion of a burner and the operation of a Stirling engine, a burner and a catalyzer. **English** (Author abstract) 12 Refs.

Tribology of small two-stroke cycle spark ignition engine fueled by methanol. (Comparison of cylinder wear by methanol, gasoline and gas fuel)
Author(s): Fujita, Naotake; Onodera, Hideki; Ito, Mitsuhiro; Iwabuchi, Akira
Author Affiliation:
Source: Nippon Kikai Gakkai Ronbunshu, C Hen/Transactions of the Japan Society of Mechanical Engineers, Part C v 63 n 611 Jul 1997 JSME Tokyo Japan p 2470-2476 0387-5024 NKCHDB
Abstract: This study deals with the tribology of small two-stroke cycle spark ignition engines fueled by methanol, gasoline and gas fuel. During the experiments, lubrication oil is supplied to the intake manifold separated from the fuels, by a carburetor. The degree of wear of each part of the cylinders was represented by the decrease in surface roughness along the sliding direction. Much decrease in surface roughness of each part of the cylinders is observed 10 hours after the start of running. It is shown that a part of a second ring of the cylinder at the top dead center shows a larger

degree of wear than the other parts. The degree of wear of each part is dependent on the kind of fuel. **Japanese** (Author abstract) 13 Refs.

Exploring the effects of SCR on a two-stroke engine
Author(s): Anon
Author Affiliation:
Source: Marine Engineers Review June 1994 Marine Management (Holdings) Ltd London Engl p 12-14 0047-5955 MRERBJ
Abstract: The problems of applying selective catalytic reduction (SCR) technology to reduce exhaust gas emissions from large marine low-speed two-stroke engines operating on heavy fuel oil are being investigated in a joint research project. A Sulzer 6RTA38 engine of 4080kW running at 200rev/min is being used to perform extensive tests to evaluate the effectiveness of SCR and its influences on the engine. Urea is used as the reducing agent and the injection rate is determined from the NO concentration measured before the catalyst. Tests are expected to determine the SCR configuration which achieves the most promising performance. Results achieved as of April 19, 1994, with the engine burning a fuel oil of HF0480 with a sulfur content of about 3.5% wt, have revealed several difficulties, but that generally an SCR plant could reduce NOx by over 90%. It revealed that SCR application needs special care due to peculiarities with regard to fuel and lubricants and type of operation. **English**

High speed video recording of fog-marked scavenging flow in a motored poppet-valved two-stroke engine
Author(s): Yang, Xiaofeng; Ishima, Tsuneaki; Obokata, Tomio
Author Affiliation: Gunma Univ
Source: SAE Special Publications Design and Performance of Two- and Four-Stroke Engines Proceedings of the 1997 International Off-Highway & Powerplant Congress & Exposition Sep 8-10 1997 v 1294 Sep 1997 Milwaukee, WI., USA, SAE Warrendale PA USA p 23-36 Paper: 972736 1054-6693 SAESA2
Abstract: A study was conducted to analyze the scavenging flow patterns in a motored two-stroke engine with air as the working fluid by means of high-speed video recording. Four kinds of cylinder heads with different port configurations were created and their effects on the scavenging flow were analyzed. The mean velocities of axial direction of scavenging flow were measured by a Laser Doppler Anemometer (LDA) and compared with the visualization images. **English** 6 Refs.

Study of two and four stroke outboard marine engine exhaust emissions using a total dilution sampling system
Author(s): Barton, Peter J.; Fearn, James
Author Affiliation: Environment Canada
Source: SAE Special Publications Design and Performance of Two- and Four-Stroke Engines Proceedings of the 1997 International Off-Highway & Powerplant Congress & Exposition Sep 8-10 1997 v 1294 Sep 1997 Milwaukee, WI., USA, SAE Warrendale PA USA p 71-80 Paper : 972740 1054-6693 SAESA2
Abstract: A study was conducted to determine if a sampling and analysis system using the total dilution constant volume sampling (CVS) system could be developed to allow exhaust emission testing to be conducted on outboard marine engines without major disassembly of the engines. During each exhaust emissions test mode, a continuously proportioned sample of the dilute exhaust mixture was continuously analyzed on a second by second basis. A sample of the dilution air was also analyzed before test mode 1 and after the final mode. **English** 9 Refs.

Effects of the catalytic converter on two-stroke engine performance
Author(s): McDowell, A.P.N.; Carberry, B.P.; Douglas, R.
Author Affiliation: Queen's Univ of Belfast
Source: SAE Special Publications Design and Performance of Two- and Four-Stroke Engines Proceedings of the 1997 International Off-Highway & Powerplant Congress & Exposition Sep 8-10 1997 v 1294 Sep 1997 Milwaukee, WI., USA, SAE Warrendale PA USA p 81-90 Paper : 972741 1054-6693 SAESA2
Abstract: To determine the effects of the catalytic converter on two-stroke engine performance, a 400 cc direct injection stroke engine with various catalysts positioned at different distances from the exhaust manifold was studied. For purposes of comparison, tests were performed between a fully lit off catalyst and a non-operational bare substrate. In addition to the effects on engine performance, cylinder trapping and burn rates were all analyzed and the differences were highlighted. **English** 8 Refs.

Catalytic after treatment and small two-stroke powered motorcycles
Author(s): Palke, D.R.; Tyo, M.A.
Author Affiliation: ASEC Manufacturing
Source: SAE Special Publications Design and Application of Two-Stroke Engines Proceedings of the 1997 International Congress and Exhibition Feb 24-27 1997 v 1254 Feb 1997 Detroit, MI., USA, SAE Warrendale PA USA p 95-104 Paper: 970800 1054-6693 SAESA2
Abstract: The development of exhaust catalysts for use with small 2-stroke engine powered 2-wheel vehicles requires an understanding of the

dynamic conditions to which they will be exposed and how they perform under these conditions. This work examines the performance characteristics of catalysts during the ECE-40 test cycle and identifies critical issues to be considered when applying catalytic after treatment to 2-stroke engine power plants. Also considered is the impact of using reed valve secondary air systems to supply additional oxygen. Emphasis is given to examining holo catalyst, secondary air, and vehicle performance are coupled to yield reduced tailpipe hydrocarbon and carbon monoxide emissions. **English** 7 Refs.

Design of a fuel-efficient uniflow two-stroke semi-direct injection engine

Author(s): Pereira, Eduardo C.O.; Rodrigues, Eurico F.A.; Martins, Jorge J.G.

Author Affiliation: Universidade do Minho

Source: SAE Special Publications Design and Application of Two-Stroke Engines Proceedings of the 1997 International Congress and Exhibition Feb 24-27 1997 v 1254 Feb 1997 Detroit, MI., USA, SAE Warrendale PA USA p 85-93 Paper: 970367 1054-6693 SAESA2

Abstract: A single cylinder small capacity uniflow two strokes engine has been designed with the sole objective of having high thermal efficiency and low specific fuel consumption, to compete in a mileage marathon. A computer code was used to predict engine performance and behavior. Theoretical study showed that the proposed goals for the competition could be largely surpassed due to the design strategy used. Friction, mass and size reducing design strategies were found to improve performance. **English** 8 Refs.

Simulation model for direct-fuel-injection of two-stroke gasoline engines

Author(s): Yu, L.; Campbell, T.; Pollock, W.

Author Affiliation: Glasgow Caledonian Univ

Source: SAE Special Publications Design and Application of Two-Stroke Engines Proceedings of the 1997 International Congress and Exhibition Feb 24-27 1997 v 1254 Feb 1997 Detroit, MI., USA, SAE Warrendale PA USA p 69-84 Paper: 970366 1054-6693 SAESA2

Abstract: A simulation model is developed for direct-fuel-injection using a multidimensional CFD code. A statistical approach is used, in which only a sample of the total population is analyzed. Two example cases are analyzed, one with the injector at the cylinder head and the other at the cylinder sidewall. Gas flow patterns, fuel droplet distributions and fuel vapor concentrations are evaluated and compared for both cases. The results lead to a conclusion that the developed model can provide an insight into

fuel spray development in two-stroke engine cylinders and thus serve as a powerful tool for the engine design. **English** 27 Refs.

Modeling the mixture formation in a small direct-injected two-stroke spark-ignition engine
Author(s): Corcione, Felice E.; Rotondi, Rossella; Gentili, Roberto; Migliaccio, Mariano
Author Affiliation: Istituto Motori
Source: SAE Special Publications Design and Application of Two-Stroke Engines Proceedings of the 1997 International Congress and Exhibition Feb 24-27 1997 v 1254 Feb 1997 Detroit, MI., USA, SAE Warrendale PA USA p 61-68 Paper: 970364 1054-6693 SAESA2
Abstract: Computations were performed to simulate the in-cylinder flow field and mixture preparation of a small port-scavenged, direct-injection, two-stroke spark-ignition engine using a modified version of the KIVA-3 code. Simulations of the interaction between airflow and fuel were performed for a commercial Piaggio (125 cc) motorcycle engine. The engine was modified to operate with a hollow cone injector located in different positions of the dome-shaped combustion chamber and in the cylinder wall. Injection location, injection pressure and timing as well as in-cylinder flow field were the most parameters to optimize the spatial distribution of the fuel. Further, the injection timing played a fundamental role to change the degree of charge stratification in the combustion volume. **English** 23 Refs.

FAST injection system: PIAGGIO solution for ULEV 2T SI engines
Author(s): Nuti, Marco; Pardini, Roberto; Caponi, David
Author Affiliation: PIAGGIO V.E. S.p.A.
Source: SAE Special Publications Design and Application of Two-Stroke Engines Proceedings of the 1997 International Congress and Exhibition Feb 24-27 1997 v 1254 Feb 1997 Detroit, MI., USA, SAE Warrendale PA USA p 45-52 Paper: 970362 1054-6693 SAESA2
Abstract: For the past years, several developments have been introduced on direct fuel injection to 2T SI engines. Among the developments, the FAST system appears to be the ultimate solution for small engine application. The entirely mechanical control of FAST guarantees a safe and electric energy consumption free alternative in the case where the use and maintenance of a battery is very difficult. **English** 12 Refs.

Proceedings of the 1997 International Congress and Exhibition
Author(s):
Author Affiliation:

Source: SAE Special Publications Design and Application of Two-Stroke Engines Proceedings of the 1997 International Congress and Exhibition Feb 24-27 1997 v 1254 Feb 1997 Detroit, MI., USA, SAE Warrendale PA USA 172p 1054-6693 SAESA2
Abstract: The proceedings contains 13 papers. Topics discussed include high speed two-stroke engine design, computational fluid dynamics, modeling the mixture formation, direct fuel injection, catalytic after treatment, noise emission measurement, air cooling system design, exhaust emissions sensitivities and two stroke engines scavenging models.

Preliminary results from a market analysis of the two-stroke combustion engine industry
Author(s): Wahla, N.; Tither, D.; Ahmed, W.; Whitaker, D.
Author Affiliation: Manchester Metropolitan Univ
Source: Technovation v 17 n 7 Jul 1997 Elsevier Science Ltd Oxford Engl p 403-408 0166-4972 TNVTDP
Abstract: Market research results from groups based in the university sector can often make a significant contribution to knowledge and perspectives related to complex international industrial sectors. This is particularly true when these groups have strong linkage to the industry in question and the market research forms part of a wider research program, which involves the science and engineering of the product base under investigation. Preliminary results are therefore presented from research focused on a market analysis of the two-stroke engine industry by members of a group which is concentrating its effort in this area of the combustion engine industry. The results are intended to introduce the work in progress and to highlight several aspects which form the core of the study including application areas, patent activity and industrial company identification. **English** (Author abstract) 10 Refs.

Tribology for small 2 stroke cycle spark ignition engine fueled by methanol
Author(s): Fujita, Naotake; Onodera, Hideki; Tsuji, Syouichi; Ito, Mitsuhiro
Author Affiliation:
Source: Nippon Kikai Gakkai Ronbunshu, C Hen/Transactions of the Japan Society of Mechanical Engineers, Part C v 60 n 571 Mar 1994 p 1027-1032 0387-5024 NKCHDB
Abstract: This study is on tribology for small two-stroke cycle spark ignition engines fueled by M85 (gasoline 15%+methanol 85%) and MO (gasoline 100%). Separation occurs when lubrication oil is added to the gasoline-methanol blended fuel. Therefore, lubrication oil is supplied to the intake manifold separately from the fuels, and the oil-to-fuel ratio is about 1:30 for MO and 1:60 for M85. Wear data for M85 under constant speed and WOT

(wide-open throttle), is compared with data of a MO counterpart. The sludge formed during engine operation was found to affect the cylinder wear performance. **English, Japanese** (Translated author abstract) 17 Refs.

Preliminary study of broadening the fuel capabilities of the direct-injected, air-assisted two-stroke engine
Author(s): Falkowski, D.T.; Abata, D.L.; Cho, P.
Author Affiliation: Michigan Technological Univ
Source: American Society of Mechanical Engineers, Internal Combustion Engine Division (Publication) ICE Combustion and Emissions Proceedings of the 1995 17th Annual ASME Fall Technical Conference of the ASME Internal Combustion Engine Division. Part 4 Sep 24-27 1995 v 4 1995 Milwaukee, WI., USA, Sponsored by: ASME ICE ASME New York NY USA p 37-45 AMEIEW
Abstract: Significant advances in two-stroke technology have been achieved with the introduction of computer-controlled, low pressure, direct fuel injection systems. Unlike premixed or port injected fuel delivery, direct injection at low pressure with appropriate combustion chamber design and improved scavenging techniques allows combustion to occur in a stratified mode at most engine loads. This study examines the feasibility of broadening the fuel capabilities of this engine because of this stratified combustion behavior. A three cylinder two stroke direct-injected engine is modified to operate on heavier, more viscous, less volatile hydrocarbons such as kerosene-based jet fuels. Demonstration of engine operation with such fuels after appropriate design modifications will significantly enhance the utilization of this engine in a variety of applications. Results have indicated that operating characteristics of this engine with jet fuel are similar to that of gasoline with respect to torque and power output. **English** (Author abstract) 17 Refs.

Research on methanol-burning, two-stroke engines
Author(s): Wilson, K.
Author Affiliation: Diesel & Gas Turbine Publications
Source: Diesel & Gas Turbine Worldwide v 26 n 4 Apr 1994 p 44-45 0278-5994 DGWODS
Abstract: In looking at the possibility of burning methanol in the two-stroke marine diesel engine, Mitsubishi has decided that its investigations would be for a pure methanol-burning engine. Since ignition of methanol by the straightforward diesel cycle is not attainable. Mitsubishi decided to use glow plugs for ignition. The result has been the adaptation of the 450 mm bore test engine, at Nagasaki, with a special cylinder head carrying tow

methanol precombustion chambers and two main methanol injectors. **English**

Advanced diagnostics for minimizing hydrocarbon emissions from a direct-injection gasoline engine

Author(s): Drake, Michael C.; French, Donald T.; Fansler, Todd D.
Author Affiliation: General Motors Research & Development Cent
Source: Symposium (International) on Combustion Proceedings of the 1996 26th International Symposium on Combustion. Part 2 (of 2) Jul 28-Aug 2 1996 v 2 1996 Napoli, Italy, Combustion Inst Pittsburg, PA USA p 2581-2587 0082-0784 SYMCAQ

Abstract: Minimizing unburned-hydrocarbon (HC) emissions at light load are essential for realizing the potential fuel-economy, cold-start, and transient-HC advantages of direct-injection (DI) stratified-charge engines. This paper summarizes the application of several advanced diagnostics to understand and quantify HC sources in an experimental DI two-stroke engine. Single-cycle (two-dimensional) and multicycle-averaged (two-dimensional and reconstructed three-dimensional) laser-induced-fluorescence (LIF) imaging of gasoline (1) characterizes the highly stratified fuel distribution at the time of ignition, (2) identifies cyclic variations in the fuel concentration near the spark gap as a principal cause of misfires and partial burns, (3) reveals regions of fuel-air mixture around the periphery of the fuel cloud that are too lean to burn, and (4) detects the out gassing of unburned fuel from the fuel injector nozzle-exit crevice late in the engine cycle. Cyclic variations are investigated further by collecting continuous, time-resolved data on liquid fuel distributions, combustion, and exhaust hydrocarbon emissions over many consecutive engine cycles. Specifically, high-speed (4000 frames/s) video imaging of the fuel spray and of spectrally resolved combustion luminosity is combined with simultaneous exhaust-HC sampling using a close-coupled fast-response (approx.2 ms) flame-ionization detector. Cylinder pressure is also digitized simultaneously, so that the imaging results can be correlated with the heat released and the exhaust HC mass for each engine cycle. The results (1) show that combustion begins as partially premixed flame propagation and ends as slower mixing-limited or diffusion burning, (2) reveal quantitatively the fate of unburned fuel in misfire and partial-burn cycles, and (3) provide strong evidence that the dominant HC sources are incomplete combustion of the injected fuel cloud and late release of fuel trapped in the injector nozzle-exit crevice (rather than fuel trapped in the piston top-ring-land crevice, which is the dominant HC source in conventional homogeneous-charge four-stroke engines). **English** (Author abstract) 8 Refs.

Global trends in two-stroke emission control technology

Author(s): Sharma, G.K.; Raje, N.R.
Author Affiliation: Indian Oil Corp Ltd
Source: American Society of Mechanical Engineers, Internal Combustion Engine Division (Publication) ICE Proceedings of the 1996 Spring Technical Conference of the ASME Internal Combustion Engine Division. Part 1 (of 9) Apr 21-24 1996 v 26-1 1996 Youngstown, OH., USA, Sponsored by: ASME New York NY USA p 1-7 AMEIEW
Abstract: Two stroke engines are very popular as a means of personal transport wherever the climatic conditions permit their use. In the last decade, two-stroke population in many countries has grown very rapidly, especially in Asian countries. While two stroke vehicles have many advantages, continued growth in their population raises serious concern regarding the health and environmental effects due to high hydrocarbon (HC) and carbon monoxide (CO) emissions from such engines. Smoke and noise emissions are also of concern. As a result, countries around the world are progressively tightening two stroke emission regulations and hence technology for reducing emission continues to advance. New engine design and research in lubricants and fuel has been targeted to reduce emissions. Besides improvement to reduce 'engine out' emissions, catalytic converters are necessary for exhaust - after treatment to meet the stringent emission regulations. Substantial progress has been made in catalytic technology and as a result two stroke engines in many countries are fitted with catalytic converters that continue to further improve. **English** (Author abstract) 47 Refs.

Cooperative application of lean burn technology to a large pipeline compressor engine
Author(s): Gillette, Allen D.; Woodford, Robert S.; McGowan, Richard J.; Heater, William R.; Lin, Chin-I.; Jennings, Richard A.; Angello, Leonard
Author Affiliation: Cooper Energy Services
Source: American Society of Mechanical Engineers, Internal Combustion Engine Division (Publication) ICE Proceedings of the 1996 18th Annual Fall Technical Conference of the ASME Internal Combustion Engine Division. Part 4 (of 5) Oct 20-23 1996 v 27-4 1996 Fairborn, OH., USA, Sponsored by: ASME ICE ASME New York NY USA p 1-8 AMEIEW
Abstract: Pacific Gas and Electric operates several two-stroke integral gas engines at compressor stations in California. Lean-burn retrofit technology has previously been developed for many of these spark-ignited units in order to reduce NOx emissions below 2 grams/Bhp-hour. However, an economical lean-burn solution had not been attempted on a certain Cooper Bessemer engine model known as the GMW, partly due to lack of previous regulatory requirements and partly due to performance uncertainties. This 1950's vintage engine is a large bore, oscillating blower-scavenged unit

with cylinder heads and combustion air passages designed well before clean air considerations. The challenge was to develop a turbocharged, precombustion chamber solution within an aggressive time schedule and practical economic expectations. A key performance requirement was to demonstrate the NOx, hydrocarbon and carbon monoxide emissions at 100% load and speed under 120°F ambient conditions. To accomplish the economic, schedule and performance requirements, a cooperative venture was established between the original equipment manufacturer, the owner/operator and the Gas Research Institute. The objective of this paper is to describe the overall project and the results of each phase, concluding with successful field performance testing. **English** (Author abstract) 6 Refs.

Comparison of fuel injection systems and a new combustion method for a direct injection two-stroke-cycle automobile engine
Author(s): Morikawa, Koji; Watanabe, Hideo; Furuya, Akira
Author Affiliation: SUBARU Research Cent Co, Ltd
Source: JSAE Review v 17 n 4 Oct 1996 Elsevier Science B.V. Amsterdam Netherlands p 401-404 0389-4304 JREVDY
Abstract: Two-stroke cycle engine as a generation power unit, have high thermal efficiency demonstrating low friction and low pumping loss. However, this efficiency is limited by mixture short circuit and light load misfiring. In connection, various fuel injection systems were studied and a prototype was built to investigate stratified charge combustion using direct fuel injection as a solution to the problems. The one-fluid high-pressure fuel system was chosen and was adopted to a single cylinder engine. Stratified charge combustion was realized using late injection, while early injection enabled high output power homogenous charge combustion. The `2-zone combustion' was achieved by injecting the fuel twice within one cycle. **English** 2 Refs.

Crank angle resolved HC-detection using LIF in the exhausts of small two-stroke engines running at high engine speed
Author(s): Andersson, Oivind; Juhlin, Greger; Ekenberg, Martin; Johansson, Bengt; Alden, Marcus
Author Affiliation: Lund Inst of Technology
Source: SAE Special Publications Diagnostics and Modeling in SI Engines Proceedings of the 1996 International Fall Fuels & Lubricants Meeting & Exposition Oct 14-17 1996 v1212 Oct 1996 San Antonio, TX., USA, SAE Warrendale PA USA p 67-76 0099-5908 SAESA2
Abstract: Laser Induced Fluorescence (LIF) was used to investigate the exhaust gases from a two-stroke SI engine in order to distinguish between emissions due to short-circuit losses and emissions due to incomplete

combustion. Laser Doppler velocimeters (LDV) measured two peaks in the emission of hydrocarbons. Spectral analysis showed that the first peak was due to incomplete combustion while the second was due to short-circuiting. Thus it was shown that two-stroke engines have two exhaust phases: in the first phase the engine emits combustion products while in the second phase it emits unburnt fuel. Finger-type cylinders were shown to be more likely to suffer short-circuiting losses than cup-type cylinders. **English** 18 Refs.

Two-stroke engine with disintegrated cycle
Author(s): Pavietic, Radislay; Leskovsek, Dejan
Author Affiliation: Univ of Ljubljana
Source: American Society of Mechanical Engineers, Internal Combustion Engine Division (Publication) ICE New Developments in Off-Highway Engines 14th Annual Fall Technical Conference of the ASME Internal Combustion Engine Division Oct 4-7 1992 v 18 1992 Sponsored by: ASME Pub by ASME New York NY USA p 155-159 AMEIEW
Abstract: Compression phase of the I.C. engine cycle was transmitted from the cylinder to its external intake system. Combustion chamber is thus filled with the pre-compressed mixture. Control of the gas flowing from the chamber to the cylinder space is controlled by a special transflow valve or by the engine piston alternatively. Volume of the tubular combustion chamber can be altered even during the operation of the engine and this is performed by a special plunger, which displacement is linked with the main control loop of the engine. Alteration of the combustion chamber volume introduces over expansion at partial engine load. Cyclic combustion variations of the tubular shaped combustion chamber, as well as its tendency to knock was observed on a model engine and has given promising results. In spite of great efforts that have been made during the last ten years in the development of conventional two-stroke engines, the required results have not been obtained. Working concept was mainly based on the simplicity of design. Sophisticated but more expensive technical solutions that could better satisfy the demands of the modern vehicle engines, i.e.: fuel economy, environment protection etc. unfortunately exceed the advantages of the simplicity of its design. Sometimes it is reasonable to sacrifice some cost-effectiveness to satisfy better performances of the engine. However, extra costs should be fully justified through all the development phases: from the basic principles, modeling and necessary performance tests to the construction of the prototype. **English** (Author abstract)

Effective energy utilization and emission reduction of the exhaust gas in a two-stroke cycle engine

Author(s): Sato, Kazuo; Ukawa, Haruo; Nakano, Masamitsu
Author Affiliation: Shibaura Inst of Technology
Source: SAE (Society of Automotive Engineers) Transactions v 100 n Sect 3 1991 p 1616-1627 Paper: 911848 0096-736X SAETA5 ASBN: 1-56091-274-X
Abstract: This paper deals with a successful attempt to employ the exhaust gases of a two-stroke cycle gasoline engine as an energy source to operate an after burner and a Stirling engine, and to clean the exhaust gases by a catalyzer. By means of a rotary valve and the exhaust pipe sections, the exhaust gases could separate into a high concentration of fresh gas and a high concentration of combustion gas. The former gas was burned by a burner, and then used to heat a Stirling engine. The latter gas was disposed of by an oxidation catalyzer. The investigation revealed the enthalpy and exergy flows of a two-stroke cycle gasoline engine, a burner, a catalyzer and a Stirling engine, and then the emission gases (HC, CO, NO) were disposed of by the burner and catalyzer. The investigative analysis shows a method of successfully transferring the energy available in the exhaust gases for the combustion of a burner and the operation of a Stirling engine, a burner and a catalyzer. **English** (Author abstract) 12 Refs

Stratified charge glow plug ignition (SCGI) engine with natural gas fuel
Author(s): Thring, Rob H.; Leet, Jeffrey A.
Author Affiliation: Southwest Research Inst
Source: SAE (Society of Automotive Engineers) Transactions v 100 n Sect 3 1991 p 1451-1461 Paper: 911767 0096-736X SAETA5 ASBN: 1-56091-274-X
Abstract: The objective was to demonstrate the feasibility of operating a natural gas two-stroke engine using glow plug ignition with very lean mixtures. Based on the results obtained, the term SCGI (stratified charge glow plug ignition) was coined to describe the engine. A JLO two-stroke diesel engine was converted first to a natural gas fueled spark-ignited engine for the baseline tests, and then to an SCGI engine. The SCGI engine used a gas-operated valve in the cylinder head to admit the natural gas fuel, and a glow plug was used as a means to initiate the combustion. The engine was successfully run, but was found to be sensitive to various conditions such as the glow plug temperature. The engine would run very lean, to an overall equivalence ratio of 0.33, offering the potential of good fuel economy and low NOx emissions. Fuel economy was compared to other natural gas engines and found to be not so good on a brake specific basis; however there was not time for much development work, and the

potential for good economy still exists. It was recommended that exhaust emissions be measured. **English** (Author abstract) 3 Refs

High-speed fuel injection system for 2-stroke D.I. gasoline engine
Author(s): Schechter, Michael M.; Jary, Eugene H.; Levin, Michael B.
Author Affiliation: Ford Motor Co
Source: SAE (Society of Automotive Engineers) Transactions v 100 n Sect 3 1991 p 967-980 Paper: 910666 0096-736X SAETA5 ASBN: 1-56091-274-X
Abstract: Two-stroke gasoline engines are known to benefit from using in-cylinder fuel injection, which improves their ability to meet the strict fuel economy and exhaust emissions requirements. A conventional method of in-cylinder fuel injection involves application of plunger-type positive displacement pumps. Two-stroke engines are usually smaller and lighter than their 4-stroke counterparts of equal power and need a pump that should also be small and light and, preferably, simple in construction. Because a 2-stroke engine fires every crankshaft revolution, its fuel injection pump must run at crankshaft speed (twice the speed of a 4-stroke engine pump). An electronically controlled fuel injection system has been designed to satisfy the needs of a small automotive 2-stroke engine capable of running at speeds of up to 6000 rpm. The fuel flow to individual engine cylinders is controlled by solenoid valves capable of one cycle response and individual cylinder adjustment of injection quantity and timing. The design and operating principles of the pump and injectors are described, and the test results of cylinder-to-cylinder distribution, cycle-to-cycle variability and fuel atomization as well as testing methods are discussed. **English** (Author abstract) 9 Refs

Air-forced fuel injection system for 2-stroke D.I. gasoline engine
Author(s): Schechter, Michael M.; Levin, Michael B.
Author Affiliation: Ford Motor Co
Source: SAE (Society of Automotive Engineers) Transactions v 100 n Sect 3 1991 p 954-966 Paper: 910664 0096-736X SAETA5 ASBN: 1-56091-274-X
Abstract: Late fuel injection directly into the cylinder of a 2-stroke engine is desirable to prevent escape of some fuel into exhaust system during cylinder scavenging. This leaves little time for fuel evaporation and mixture preparation and puts a premium on the degree of fuel atomization needed during the injection process. Although a respectable degree of atomization can be attained in fuel systems with high pressure, liquid-only injection, further improvements can be made when compressed air is used to assist atomization. A novel air-forced (AFI) fuel injection system for in-cylinder injection in a 2-stroke engine is described. The system employs

compressed air to force a metered quantity of fuel from the fuel injector internal cavity past a spring-loaded poppet valve. A fog-like cloud containing a rich mixture of fuel and air is injected into the cylinder. As a result, an exceptionally fine atomization is achieved. At the same time, the shape of the air-fuel mixture spray can be varied as may be required by engine operating conditions. The basic concept and operating principles of 2 generations of AFI systems are reviewed together with advantages and shortcomings of both systems. The injector flow test results, injection stability and fuel atomization are discussed. Use of the Coanda effect to create various spray shapes is demonstrated. **English** (Author abstract) 15 Refs

Much better prospects for two stroke technology
Author(s): Eisenhauer, Karl
Author Affiliation:
Source: Automotive Engineer (London) v21 n2 Apr-May 1996 MEP Edmunds Engl 4pp 0307-6490 EUENDA
Abstract: Orbital has been working on a fuel efficient, low emission and high specific output two-stroke engine for automotive use. Recognizing that if the two-stroke engine is to be released into the market, its reliability and durability expectations must match or surpass those of its four stroke production competitors. Over the last 18 months, Orbital has been working on durability and lubrication development. **English**

Developments in two-stroke cycle engine exhaust emissions
Author(s): Kenny, R.G.
Author Affiliation: Queen's Univ of Belfast
Source: Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering v 206 n 2 1992 p 93-106 0954-4070 PMDEEA
Abstract: This paper is concerned with the exhaust emissions from two-stroke cycle spark ignition engines and the means being investigated to reduce them. The simple two-stroke engine has inherently low levels of NOx emissions and high levels of hydrocarbon emissions. The reasons for these emissions characteristics are explained by reference to the open literature. The two-stroke engine is used in a wide range of applications including low-cost, low-output mopeds and high-performance motorcycles. More recently there has been a resurgence of interest in the two-stroke as an alternative to the four-stroke engine for automotive use. A number of the recently reported approaches to emissions control are reviewed, including the use of exhaust oxidation catalysts in simple low-cost engines and direct fuel injection on more costly, multi-cylinder engines. **English** (Author abstract) 47 Refs

Characterization of ignition and parametric study of a two-stroke-cycle direct-injected gasoline engine
Author(s): Abata, Duane; Wellenkotter, Kurt
Author Affiliation: Michigan Technological Univ
Source: SAE Technical Paper Series International Congress and Exposition Feb 24-28 1992 1992 Pub by SAE Warrendale PA USA p 103-114 Paper: 920423 0148-7191 STPSDN
Abstract: A study of the early stages of combustion in a two-stroke-cycle, direct-injection engine was conducted with the aid of two tools which are both newly applied to the two-stroke; optical photography and in-cylinder hydrocarbon measurement. The data helps to understand how the intake air rate and fuel injection parameters affect delivery of the fuel charge to the spark gap and subsequent combustion quality. The conclusions of this study are intended to serve as a first step in empirically understanding the influence of the time-variant bulk and turbulent flows which are responsible for dissipation and motion of the direct injection fuel cloud. **English** (Author abstract) 11 Refs

Combustion and emissions of low heat rejection ceramic methanol ATAC engines
Author(s): Iida, Norimasa; Hosonuma, Shinji; Yoshimura, Ken'ichi; Takase, Shigehisa
Author Affiliation: Keio Univ
Source: JSME International Journal, Series B: Fluids and Thermal Engineering v39 n1 Feb 1996 JSME Tokyo Japan p 176-184 1340-8054 JSFPET
Abstract: When methanol is used as fuel for internal combustion engines, formaldehyde and unburned methanol emissions can be a problem. To overcome this shortcoming, an engine with the active thermo-atmosphere combustion (ATAC) system was proposed, along with improvements in heat-insulating performance and the realization of high-temperature combustion by using ceramics for the combustion chamber walls. The combustion and emissions characteristics of this ceramic low heat rejection (LHR) methanol ATAC engine were investigated. Combustion performance was compared between operation with methanol and gasoline. When methanol was used, it was seen that the ATAC operation region was widened considerably. Also, a reduction in aldehyde emissions was achieved, due to the high-temperature operation of the combustion chamber. However, efficiency deteriorated at times due to early self-ignition timing. This was overcome by the use of lean fuel-air ratios, which resulted in both a reduction of NOx and an improvement in fuel consumption. With a premixed fuel supply system, wall surface ignition was unavoidable for

combustion chamber surface temperatures greater than 800 K (527°C). Wall surface temperature swing and instantaneous heat flux increased substantially with ATAC operation under these conditions. **English** (Author abstract) 6 Refs.

Fuel Systems and General Emissions
Author(s):
Author Affiliation:
Source: SAE Special Publications Fuel Systems and General Emissions International Congress and Exposition Feb 24-28 1992 n 910 1992 Pub by SAE Warrendale PA USA 206p 0099-5908 SAESA2 ASBN: 1-56091-227-8
Abstract: Twenty conference papers are presented in this volume. Main topics include fuel economy, exhaust emissions, fuel systems, combustion, catalysts, fuels and related control processes, measurement and control of exhaust emissions, electrically heated catalyst systems, emission anlysers and tests, and exhaust gas recirculation. **English**

Performance and exhaust emissions of a two-stroke spark-ignition engine with a direct-injection system
Author(s): Daisho, Yasuhiro; Saito, Takeshi; Ishibe, Noriaki; Tsukada, Mitsuhiro; Yukawa, Masashi
Author Affiliation: Waseda Univ
Source: International Journal of Environment and Pollution v 1 n 1-2 1991 p 113-124 0957-4352 IJEOEF
Abstract: A direct fuel-injection system has been adapted to a small two-stroke spark-ignition engine to prevent the charge from flowing through the cylinder during the scavenging process. The injection system consists of a jerk-type pump and a single-hole nozzle which supplies gasoline to the cylinder. Engine tests were carried out for comparison with the carburetor version of the same engine. The results show that the direct-injection version can achieve greatly improved thermal efficiency and lower HC and CO emissions without intake throttling. In addition, NOx can be reduced to a much lower level than that of the ordinary four-stroke engine. Heat release analysis and high-speed photography indicate that stratified charge combustion takes place in the direct-injection engine. **English** (Author abstract) 5 Refs

Velocity field characteristics in motored two-stroke ported engines
Author(s): Ghandhi, Jamshed B.; Martin, Jay K.
Author Affiliation: Becton Dickinson Research Cent
Source: SAE Special Publications Two-Stroke Engine Diagnostics and Design International Congress and Exposition Feb 24-28 1992 n 901 1992

Pub by SAE Warrendale PA USA p 45-55 0099-5908 SAESA2 ASBN: 1-56091-218-9

Abstract: Particle image velocimetry (PIV) was used to study the velocity field characteristics in motored two-stroke ported engines. Measurements of the two-dimensional velocity field were made at the midplane of the clearance volume for bowl-in-head and disk combustion chamber geometries. Measurements were also obtained for two scavenging port geometries, i.e. a loop-scavenged engine and a loop-scavenged engine with a boost port. Results from this study show that in-cylinder geometry had a dominant effect on the flow structure observed at TDC. For example, with the boost-port scavenging crankcase, the disk-shaped chamber showed a turbulent flow-field at TDC with little large-scale motion. In contrast, addition of a squish flow from the bowl-in-head geometry produced an organized cross-chamber flow. The addition of a boost port also changed the flow structure markedly. A large-scale swirl flow was observed in the engine that did not contain a boost port. In contrast, the boost port apparently breaks down the tendency to swirl. **English** (Author abstract) 15 Refs

Characterization of ignition and parametric study of a two-stroke-cycle direct-injected gasoline engine

Author(s): Abata, Duane; Wellenkotter, Kurt

Author Affiliation: Michigan Technological Univ

Source: SAE Special Publications Two-Stroke Engine Diagnostics and Design International Congress and Exposition Feb 24-28 1992 n 901 1992 Pub by SAE Warrendale PA USA p 103-114 0099-5908 SAESA2 ASBN: 1-56091-218-9

Abstract: A study of the early stages of combustion in a two-stroke-cycle, direct-injection engine was conducted with the aid of two tools which are both newly applied to the two-stroke; optical photography and in-cylinder hydrocarbon measurement. The data helps to understand how the intake air rate and fuel injection parameters affect delivery of the fuel charge to the spark gap and subsequent combustion quality. The conclusions of this study are intended to serve as a first step in empirically understanding the influence of the time-variant bulk and turbulent flows, which are responsible for dissipation, and motion of the direct injection fuel cloud. **English** (Author abstract) 11 Refs

Appraisal of regenerative blowers for scavenging of small 2T S.I. power plants
Author(s): Cundari, Dario; Nuti, Marco
Author Affiliation: Piaggio V.E.
Source: SAE Special Publications Two-Stroke Engine Diagnostics and Design International Congress and Exposition Feb 24-28 1992 n 901 1992 Pub by SAE Warrendale PA USA p 207-215 0099-5908 SAESA2 ASBN: 1-56091-218-9
Abstract: The nowadays two-stroke engine technique is directed toward new concepts to reduce fuel consumption and pollution. Typical features are direct injection of fuel and no lost oil lubrication: a separate scavenging system is becoming so a must. Following general consideration about different scavenging pumps, a regenerative blower solution is proposed. Regenerative blowers present in fact several advantages in comparison with other solutions like simplicity in construction and on engine fitting, no maintenance and low cost. An exhaustive experimental evaluation was carried out on a direct injection two-stroke S.I. engine with a separate scavenge, already described in a previous work by one of the authors. The results show the practical feasibility of the proposed solution. In fact, the regenerative blower is suitable to match the engine air breath demand all over its utilization range. Concluding remarks relative to possible layout for light power plants, like small vehicles and marine engines, are presented in the last part of the present paper.

Two-Stroke Engines, Small Engines and Emission Reduction
Author(s):
Author Affiliation:
Source: SAE Special Publications Two-Stroke Engines, Small Engines and Emission Reduction International Off-Highway and Power plant Congress and Exhibition Sep 9-12 1991 n 883 Sep 1991 Pub by SAE Warrendale PA USA 172p 0099-5908 SAESA2 ASBN: 1-56091-175-1
Abstract: This Conference Proceedings contains 12 papers devoted to methods in reduction of pollutants from small, two-stroke, engines, which are used mostly as marine outboard engines, in chain saws, lawn mowers and other agricultural implements. Emission topics include: electronic and air-assisted fuel injection, catalytic conversion, exhaust gas recirculation, as well as the utilization of exhaust gas energy. **English**

1991 Small Engine Technology Conference Proceedings
Author(s):
Author Affiliation:
Source: 91 Small Engine Technol Conf Proc 1991 Small Engine Technology Conference Proceedings Oct 1991 Pub by Soc of Automotive Engineers of Japan Tokyo Jpn 744p
Abstract: This conference proceeding contains 84 papers. Some of the topics discussed by the papers are here cited as examples: development of fuel injected two-stroke outboard motor; piston friction losses in high-speed engines; track belt for snowmobile; disc brake for motorcycles; hybrid scooter: a proposal for urban areas commuting; a study on the variations of combustion characteristics in diesel engine; unitized power unit for compact lawn tractor; development of high-speed auto-mesh program for FEM analysis; a new challenge for high-performance two-cycle engine oils, Part-II: biodegradable oil; development of SiC whiskers reinforced piston; sealed nickel-zinc battery for electric mower uses; the pulsed Yag Laser welding of an austenitic steel sheet to decrease the weld distortion; abnormal combustion in methanol-fueled, crankcase-scavenged two-stroke engines--a theoretical study; investigation on thermal loading of the high speed small air-cooled diesel engines; and super cross race and racing machine.
English

Development of programmed-fuel injection for two-stroke cycle racer engine
Author(s): Kusano, Katsuyuki; Kurosaka, Hitoshi
Author Affiliation: Honda R&D Co, Ltd
Source: 91 Small Engine Technol Conf Proc 1991 Small Engine Technology Conference Proceedings Oct 1991 1991 Pub by Soc of Automotive Engineers of Japan Tokyo Jpn p 39-47
Abstract: An electronically controlled fuel injection system for controlling the air/fuel (A/F) ratio has been looked forward as a means for improving drivability, output characteristics, and fuel consumption of two-stroke cycle motorcycle racer engines. However, actual installation of such a system on a high output two-stroke cycle engine (which utilizes exhaust gas pressure pulsation effects) has been considered difficult for the following reasons. Fluctuation in the delivery ratio (L) during firing and misfiring becomes great due to effects from the exhaust pipe. Applying the control method used for conventional four-stroke cycle engines (by which the delivery ratio (L) is measured) would necessitate a large and heavy system. The authors have eliminated such problems by developing an electronically controlled fuel injection system, the PGM-FI (Programmed-Fuel Injection) system, which employs basic intake air flow data according to engine speed (NE) and throttle opening (?TH). Compensation for the delivery ratio (L) fluctuation in

low throttle opening regions is carried out for depression at engine manifold (PB), while that in high throttle opening regions is carried out for combustion pressure (PI). Compensation is also enabled for ambient temperature (TA), ambient pressure (PA), cooling water temperature (TW), and exhaust gas temperature (TEXH), thus establishing a control method, which is uninfluenced by operational conditions. The following paper discusses an example of applying this newly developed PGM-FI system on a two-stroke cycle motorcycle racer engine, whereby all the compensations mentioned above were made effective. **English** (Author abstract) 2 Refs

Development of fuel injected two-stroke outboard motor
Author(s): Mishima, Shuichi
Author Affiliation: Suzuki Motor Corp
Source: 91 Small Engine Technol Conf Proc 1991 Small Engine Technology Conference Proceedings Oct 1991 1991 Pub by Soc of Automotive Engineers of Japan Tokyo Jpn p 49-56
Abstract: The 2-stroke, 2.7-liter, V-6, 165.5kw (225ps) outboard motor with a fuel injection unit was developed using the existing V-6 outboard motor with carburetor specifications as a base. The new outboard motor assures adequate reliability, along with significantly improved performance over the existing V-6 outboard motor, in terms of output, specific fuel consumption and quiet operation. This paper will summarize the particulars of development in the course of describing the construction and features of the power-unit. **English** (Author abstract)

Development of automatic exhaust valve control device of 2-stroke engines
Author(s): Fujikawa, Tetsuzo; Ohtsu, Makoto
Author Affiliation: Kawasaki Heavy Industries Ltd
Source: 91 Small Engine Technol Conf Proc 1991 Small Engine Technology Conference Proceedings Oct 1991 1991 Pub by Soc of Automotive Engineers of Japan Tokyo Jpn p 57-65
Abstract: Recently, motocross racetrack configurations have been changing from speed-oriented layouts to rider's talented performance-oriented layouts. This has created a demand for engines that can provide both power at high speeds and torque at low speeds as well as having quick response at all speeds. The most efficient way to achieve all round power range in the 2-stroke-racing engine was to increase the area of exhaust port and to vary the exhaust chamber volume at the same rate as the increased engine revolution. The authors developed an automatic exhaust control valve device called 'KIPS'. In this paper we will describe how KIPS was developed, its output characteristics, and operation. Figure I

shows a 1992 model KX250 motocross racing bike equipped with the newest KIPS device (3-Way KIPS). **English** (Author abstract)

Development of advanced digital engine control system for outboard motors
Author(s): Kojima, Akinori; Umemoto, Hideki
Author Affiliation: Sanshin Industries Co Ltd
Source: 91 Small Engine Technol Conf Proc 1991 Small Engine Technology Conference Proceedings Oct 1991 Pub by Soc of Automotive Engineers of Japan Tokyo Jpn p 67-75
Abstract: A new 3.1 liter two-stroke-cycle V6 engine has been developed for the big power outboard motor VX model. This engine has the complex digital engine control system, which was developed for the essential properties of high output, all-round running performance, and quick start. The properties are required to meet the larger marine engine market demand, and must be backed up with positive reliability. The system comprises a multipolar alternator with ample capacity of 12V 35A to satisfy the demands from larger outboard motor, and a CDI unit to control the spark timing and fuel enrichment, and also to provide the diagnostic function. Necessary data for the system is input by the sensors monitoring crankshaft position, throttle angle, knocking, oil level, trim angle, and coolant temperature. Based on these data, the system outputs: control signals for spark timing, fuel enrichment, and oil feed pump operation; engine cpm and oil display; over heat warning; and diagnostic function. Also the system is specially constructed to fit for the severe environments in which marine engines are normally used: waterproof direct-in connector with the wet environment; back-up power system under low battery condition; electrical noise proof design. **English** (Author abstract)

IAPAC compressed air assisted fuel injection for high efficiency low emissions marine outboard two-stroke engines
Author(s): Monnier, Gaetan; Duret, Pierre; Glover, Stephen
Author Affiliation: Inst Francais du Petrole
Source: 91 Small Engine Technol Conf Proc 1991 Small Engine Technology Conference Proceedings Oct 1991 Pub by Soc of Automotive Engineers of Japan Tokyo Jpn p 215-230
Abstract: The implementation of the IFP-developed Compressed Air Assisted Fuel Injection process (named IAPAC) on a two-stroke engine allows the introduction of the fuel separately from the scavenging air in order to minimize fuel short-circuiting. The IAPAC process does not require an external air pump since the compressed air used to atomize the fuel is supplied, at no expense, by the crankcase. The premixed charge is delivered directly into the cylinder with a high spray quality and its

stratification, for optimized combustion, is controlled by a valve. This process, therefore, provides the advantages of the direct injection but uses conventional low-pressure automotive type injection technology with commercially available gasoline injectors. In earlier work we showed how the qualities of light weight, compactness, high specific power, high efficiency and low emissions make this concept particularly well-adapted for future automotive applications. Marine engine exhaust emissions from most conventional 2-stroke engines are excessive and future legislation will no doubt take this fact into account. In this paper we show how IAPAC technology provides an interesting solution to significantly reduce the pollutant emissions and improve the fuel economy of 2-stroke outboard engines. A 3-cylinder 1,2L marine outboard IAPAC2-stroke engine has been developed and extensively tested. The results obtained point out that, with maintained quality of compactness and power output, this new engine gives fuel consumption reductions of more than 25% and unburned hydrocarbon emission reductions of 70 to 90%. Pollutant emissions are evaluated according to the ICOMIA and ISO procedures and the results clearly show how the IAPAC system is well adapted to take optimum advantage of the two-stroke cycle principle in marine outboard engine applications. A description of new IFP innovative technologies, derived from IAPAC, is also presented. The concept of using compressed air to assist fuel injection is always maintained in all these technologies. **English** (Author abstract) 22 Refs

Application of a low-pressure air-assisted fuel injection system on two-stroke motorcycle

Author(s): Wang, James H.; Huang, Huei-Huay; Peng, Yu-Yin; Horng, Rong-Fang; Wang, Wen-Bin

Author Affiliation: Industrial Technology Research Inst

Source: 91 Small Engine Technol Conf Proc 1991 Small Engine Technology Conference Proceedings Oct 1991 Pub by Soc of Automotive Engineers of Japan Tokyo Jpn p 239-247

Abstract: A low-pressure air-assisted fuel injection system has been applied to a 2-stroke motorcycle to reduce the fuel consumption and emissions. This system injected atomized fuel into cylinder through a nozzle located in cylinder wall and resulted in fuel economy and emission improvements. In the ECE40 test, the average fuel consumption and hydrocarbon emission of the fuel-injected motorcycle were reduced by 27.5% and 38.3% compared to the carburetor version. **English** (Author abstract) 9 Refs

Study of exhaust emission reduction and lubricity of two stroke engine

Author(s): Lai, Shin-Tsun; Sheng, Jack P.M.; Lin, Cheng-Shyong; Lin, Ron Sheng; Lin, Chen-Yl; Shiau, Yo-Fu; Huang, Gibbs G.S.
Author Affiliation: Chinese Petroleum Corp
Source: 91 Small Engine Technol Conf Proc 1991 Small Engine Technology Conference Proceedings Oct 1991 Pub by Soc of Automotive Engineers of Japan Tokyo Jpn p 427-438
Abstract: This paper discussed the results of the exhaust emission (HC, CO & Smoke) and lubricity of two stroke engines for motorcycles. Three different displacements 150c.c., 125c.c. and 49c.c. air cooled type, two stroke engines were employed in this study. Results showed that the emission of HC and CO were not significantly changed by varying oil/fuel ratio, but the visible smoke could be reduced by leaner oil/fuel ratio. The HC and CO emission and visible smoke were reduced in the polybutene containing oils. Higher molecular weight polybutene were more effective for the reduction of smoke. In view of the lubricity performances, it was found that higher molecular weight polybutene caused the piston skirt scuffing and spark plug fouling problems, and also had a negative effect on piston cleanliness. The combination of low ash type additives with some ashless dispersants improved engine cleanliness and ring sticking. **English** (Author abstract) 8 Refs

Two-stroke ported engine with scavenging pump. Prototype and results
Author(s): Laforgia, Domenico
Author Affiliation: Univ di Bari
Source: 91 Small Engine Technol Conf Proc 1991 Small Engine Technology Conference Proceedings Oct 1991 Pub by Soc of Automotive Engineers of Japan Tokyo Jpn p 531-538
Abstract: A mono-cylinder engine was built, because of its costs and the simplicity of designing, as flexible prototype. A scavenging system with four ports, two by two symmetrical, was chosen to respect the modern theory of scavenging optimization. The scavenging flow was supplied by a carter-pump; it has been used as first experimental solution. The prototype has been entirely realized and the following experimental measurements have been carried out: the pressure in combustion chamber, in carter pump, in pipes and injection system, as well as the fundamental parameters of engine functioning. **English** (Author abstract) 7 Refs

Experimental research of labyrinth airhead scavenging project. For reducing idling pollutants from two-stroke motorcycle
Author(s): Sheng, Bai Jing; Song Qin, Wang; Qiang, Feng Fu; Hong, Chen Shao; Sen, Zhang Dong; Hong, Sun; Cheng, Zhao Jin; Hong, Shi
Author Affiliation: Tianjin Motorcycle Engine Research Inst

Source: 91 Small Engine Technol Conf Proc 1991 Small Engine Technology Conference Proceedings Oct 1991 Pub by Soc of Automotive Engineers of Japan Tokyo Jpn p 651-659
Abstract: The key point of reducing idling pollutants from two-stroke engines is to improve gas exchanging quality. This paper proposed a new construction of airhead scavenging project- labyrinth airhead scavenging project. Test results prove that this project together with delaying ignition timing, increasing idling delivery ratio and high-energy ignition can make the idling pollutants of 1E46FM engine reducing from HC gt; 8000 ppm to 5800 ppm and CO from 4.8% to <2.0%. **English** (Author abstract) 7 Refs

Snowmobile 340ccm formula 1 - and Kart 100ccm racing engines. Two extremes in terms of high-performance two-stroke engine layouts
Author(s): Holzleitner, Hans
Author Affiliation: Rotax GmbH
Source: 91 Small Engine Technol Conf Proc 1991 Small Engine Technology Conference Proceedings Oct 1991 Pub by Soc of Automotive Engineers of Japan Tokyo Jpn p 727-735
Abstract: Two-stroke racing engines are nowadays in a very high-developed stage and are used specially in racing disciplines, where extremely high power-to-weight ratios are required. But the type of racing sometimes leads to a completely different demand in performance and power band. Two of these contrary applications are Kart and snowmobile racing. This investigation shows, why the demand is so different and what measures on the engines have to be taken, to accomplish these requirements. **English** (Author abstract)

Closed cycle simulation model with particular reference to two-stroke cycle engines
Author(s): Reid, Michael G.; Douglas, Roy
Author Affiliation: Queen's Univ of Belfast
Source: SAE Special Publications Two-Stroke Engines, Small Engines and Emission Reduction International Off-Highway and Power plant Congress and Exhibition Sep 9-12 1991 n 883 Sep 1991 Pub by SAE Warrendale PA USA p 99-110 0099-5908 SAESA2 ASBN: 1-56091-175-1
Abstract: A quasi-dimensional computer simulation model is presented to simulate the thermodynamic and chemical processes occurring within a spark ignition engine during compression, combustion and expansion based upon the laws of thermodynamics and the theory of equilibrium. A two-zone combustion model, with a spherically expanding flame front originating from the spark location, is applied. The flame speed is calculated by the application of a turbulent entrainment propagation model.

A simplified theory for the prediction of in-cylinder charge motion is proposed which calculates the mean turbulence intensity and scale at any time during the closed cycle. It is then used to describe both heat transfer and turbulent flame propagation. The model has been designed specifically for the two-stroke cycle engine and facilitates seven of the most common combustion chamber geometries. The fundamental theory is nevertheless applicable to any four-stroke cycle engine. The model has been evaluated by the comparison of measured and predicted pressure traces and heat release rates. The results show good agreement across the whole data set. **English** (Author abstract) 31 Refs

Effective energy utilization and emission reduction of the exhaust gas in a two-stroke cycle engine
Author(s): Sato, Kazuo; Ukawa, Haruo; Nakano, Masamitsu
Author Affiliation: Shibaura Inst of Technology
Source: SAE Special Publications Two-Stroke Engines, Small Engines and Emission Reduction International Off-Highway and Power plant Congress and Exhibition Sep 9-12 1991 n 883 Sep 1991 Pub by SAE Warrendale PA USA p 111-122 0099-5908 SAESA2 ASBN: 1-56091-175-1
Abstract: This paper deals with a successful attempt to employ the exhaust gases of a two-stroke cycle gasoline engine as an energy source to operate an after burner and a Stirling engine, and to clean the exhaust gases by a catalyzer. By means of a rotary valve and the exhaust pipe sections, the exhaust gases could be separated into a high concentration of fresh gas and a high concentration of combustion gas. The former gas was burned by a burner, and then used to heat a Stirling engine. The latter gas was disposed of by an oxidation catalyzer. The investigation revealed the enthalpy and exergy flows of a two-stroke cycle gasoline engine, a burner, a catalyzer and a Stirling engine, and then the emission gases (HC, CO, NO) were disposed of by the burner and catalyzer. The investigative analysis shows a method of successfully transferring the energy available in the exhaust gases for the combustion of a burner and the operation of a Stirling engine, a burner and a catalyzer. **English** (Author abstract) 12 Refs

IAPAC compressed Air Assisted Fuel Injection for high efficiency low emissions marine outboard two-stroke engines
Author(s): Monnier, Gaeetan; Duret, Pierre
Author Affiliation: Inst Francais du Petrole (IFP)
Source: SAE Special Publications Two-Stroke Engines, Small Engines and Emission Reduction International Off-Highway and Power plant Congress and Exhibition Sep 9-12 1991 n 883 Sep 1991 Pub by SAE Warrendale PA USA p 123-135 0099-5908 SAESA2 ASBN: 1-56091-175-1

Abstract: The implementation of the Compressed Air Assisted Fuel Injection process on a two-stroke engine allows the introduction of the fuel separately from the scavenging air in order to minimize fuel short-circuiting. Since most marine engines generate emissions, a suggestion is made here how to reduce gaseous effluents from two-stroke marine engines. **English** 18 Refs

High-speed fuel injection system for 2-stroke D.I. gasoline engine
Author(s): Schechter, Michael M.; Jary, Eugene H.; Levin, Michael B.
Author Affiliation: Ford Motor Co
Source: SAE Technical Paper Series International Congress and Exposition Feb 25-Mar 1 1991 1991 Pub by SAE Warrendale PA USA 14p Paper: 910666 0148-7191 STPSDN
Abstract: Two-stroke gasoline engines are known to benefit from using in-cylinder fuel injection which improves their ability to meet the strict fuel economy and exhaust emissions requirements. A conventional method of incylinder fuel injection involves application of plunger-type positive displacement pumps. Two-stroke engines are usually smaller and lighter than their 4-stroke counterparts of equal power and need a pump that should also be small and light and, preferably, simple in construction. Because a 2-stroke engine fires every crankshaft revolution, its fuel injection pump must run at crankshaft speed (twice the speed of a 4-stroke engine pump). An electronically controlled fuel injection system has been designed to satisfy the needs of a small automotive 2-stroke engine capable of running at speeds of up to 6000 rpm. The fuel flow to individual engine cylinders is controlled by solenoid valves capable of one cycle response and individual cylinder adjustment of injection quantity and timing. The design and operating principles of the pump and injectors are described, and the test results of cylinder-to-cylinder distribution, cycle-to-cycle variability and fuel atomization as well as testing methods are discussed. **English** (Author abstract) 9 Refs

Two-stroke engine technology in the 1990's
Author(s): Wyczalek, Floyd A.
Author Affiliation: Fwlilly Inc
Source: SAE Technical Paper Series International Congress and Exposition Feb 25-Mar 1 1991 1991 Pub by SAE Warrendale PA USA 8p Paper: 910663 0148-7191 STPSDN
Abstract: This is an assessment of current two-stroke automotive engine technology, implementation policy, vision, goals, and engine development and commercialization strategy. It includes a historical review of key two-stroke Otto cycle and Diesel cycle engine developments, a summary of the specifications for the new: Toyota S-2 gasoline and S-2 Diesel engines,

Subaru Super 2-stroke, Orbital two-stroke engine series, and Industrial Technology Research Institute (ITRI) two-stroke technology in Taiwan. Although two-stroke engine technology has been under development since the end of the 19th century, currently the only mass produced vehicles powered by two-stroke cycle engines are the Trabant and Wartburg, with 594 cc two cylinder and 993 cc three cylinder engines, respectively, essentially unchanged in cylinder configuration and porting since 1931. VEB Sachsenring Automobilwerke Zwickau-Trabant and VEB Automobilwerke Eisenach-Wartburg are the manufacturing plants in East Germany, (GDR). Annual production peaked in 1987 at about 218,000 cars per year, but declined to 146,000 Trabant two-stroke vehicles by 1989, when, in the Autumn of 1988, the Wartburg switched to the four-stroke 1.3L4 VW engine. Furthermore, Trabant will switch to the four-stroke 1.0L4 VW Polo and two-stroke engine production essentially ended September 1990, because the Trabant/Wartburg two-stroke engines do not meet the vehicle performance and exhaust emission standards of West Germany (FRG). On the other hand, in Australia, Japan, Taiwan and the United States interest in the development of two-stroke automotive spark ignition engines has increased significantly. Because of this revival of activity in America and the Orient, coupled with the contrary switch from two-stroke to four-stroke cycle gasoline engine production in Europe, this assessment was undertaken to determine the prospects for two-stroke mass production in the Western and Oriental nations. **English** (Author abstract) 33 Refs

AFR and emissions calculations for two-stroke cycle engines
Author(s): Douglas, Roy
Author Affiliation: Queen's Univ of Belfast
Source: SAE (Society of Automotive Engineers) Transactions v 99 n Sect 3 1990 p 1909-1920 0096-736X SAETA5
Abstract: This paper demonstrates the very useful technique of calculating air-to-fuel ratio, AFR, from exhaust gas emissions for a two-stroke cycle engine. Such methods are widely used for four-stroke engines where direct airflow measurement has now become redundant. Two modified methods are presented and compared with three standard methods, showing the accuracy to be quite good for a large set of test data from a standard two-stroke engine. A procedure for estimating AFR of the in-cylinder burning region, using trapping efficiencies, is presented for stratified charge engines, such as those with direct fuel injection. Accuracy of emissions measurement is assessed by calculating the total dry exhaust emissions, a method which could easily be automated for general test cell use. Finally, exhaust gas molecular weight and wet/dry ratio calculations are considered. **English** (Author abstract) 16 Refs

500cc Two-stroke engines for mopeds, chainsaws and motorcycles with catalysts
Author(s): Laimbock, Franz J.; Landerl, Christian J.
Author Affiliation: Graz Univ of Technology
Source: SAE (Society of Automotive Engineers) Transactions v 99 n Sect 3 1990 p 1888-1908 0096-736X SAETA5
Abstract: 4 different engine concepts with Catalyst have been developed in regard to pollutant emission, fuel efficiency and performance. Despite the wide power range from 1,2 HP to 12 HP and the different applications of these engines to Mopeds, Chainsaws and Motorcycles, the problems to solve have been similar. Internal measures such as optimized carburetion, cooling, piston shape and clearance, scavenging and tuning of the exhaust must enable the engine to run on the lean side. This is imperative to supply sufficient oxygen for the exothermal reaction and to keep the energy to be converted in the Oxidation Catalyst at a minimum. Secondary measures have been taken to shorten the Catalyst's light off and to keep the temperature range in limits. **English** (Author abstract) 19 Refs

Reduction of pollutant emissions of the IAPAC two-stroke engine with compressed air assisted fuel injection
Author(s): Duret, Pierre; Moreau, Jean-Francois
Author Affiliation: Inst Francais du Petrole (IFP)
Source: SAE (Society of Automotive Engineers) Transactions v 99 n Sect 3 1990 p 1641-1656 0096-736X SAETA5
Abstract: The implantation of the IFP-developed Compressed Air Assisted Fuel Injection process (IAPAC) in a two-stroke engine allows the introduction of the fuel separately from the scavenging air, in order to minimize fuel short-circuiting. In earlier work, we achieved a drastic reduction of emissions using the IAPAC fuel injection process. Here, we give a precise analysis of the origin of the remaining pollution. The purpose of this analysis is to evaluate the real potential of a high efficiency two-stroke engine in comparison to conventional four-stroke engines, and to define the areas most needful of further development. The new results obtained pointed out how the IAPAC system is particularly well adapted to take optimum advantages of the two-stroke-cycle principle. **English** (Author abstract)

Motored and steady flow boundary conditions applied to the prediction of scavenging flow in a loop scavenged two-stroke cycle engine
Author(s): Smyth, J.G.; Kenny, R.G.; Blair, G.P.
Author Affiliation: Queen's Univ of Belfast

Source: SAE (Society of Automotive Engineers) Transactions v 99 n Sect 3 1990 p 1624-1640 0096-736X SAETA5
Abstract: The application of in-cylinder multi-dimensional modeling to the scavenging process within the cylinder of a two-stroke cycle engine requires a prior knowledge of the flow entering that cylinder. Without this information, assumptions must be made which limit the accuracy of the theoretical simulation. This paper describes laser doppler anemometry measurements of transfer port efflux flow for a two-port loop scavenged test cylinder motored at 200 rev/min. The cylinder was externally blown to ensure scavenge flow into the cylinder over the entire transfer port open period. The test results indicate that the flow does not enter the cylinder in the port design direction, but varies as a function of port height during both port opening and closing. Comparison of motoring results with those obtained under steady flow testing of the same cylinder shows adequate correlation, thereby justifying the use of steady flow information for dynamic simulation. Incorporation of the measured LDA results as boundary conditions to the multi-dimensional modeling of isothermal scavenging produces very good correlation with experimental data. The predictions, obtained with the use of experimentally measured boundary conditions, are compared with those obtained using an assumption that flow enters the cylinder in the port design direction. Contour plots of the predicted in-cylinder fresh charge concentration are presented, which highlight the sensitivity of the scavenge process to the application of differing boundary conditions at cylinder entry. **English** (Author abstract)

Two-stroke engines: cleaner and meaner
Author(s): Siuru, Bill
Author Affiliation: Mechanical Engineering
Source: Mechanical Engineering v 112 n 6 Jun 1990 p 66-69 0025-6501 MEENAH
Abstract: Advanced technologies such as direct fuel injection and stratified charge combustion have turned the two-stroke engine, which was once considered crude, dirty, and fuel thirsty, into a clean, fuel economic powerhouse. General Motors and Toyota are already testing prototype designs. **English** (Author abstract)

Modeling of reed valves. Application to 2-S internal combustion engines
Author(s): Royo, Rafael; Perez, Antonio
Author Affiliation: Universidad Politecnica de Valencia
Source: American Society of Mechanical Engineers, Internal Combustion Engine Division (Publication) ICE Engine Modeling Proceedings of the ASME Internal Combustion Engine Division Spring Meeting Apr 23-26 1995

v23 1995 Marietta, OH., USA, Sponsored by: ASME ASME New York NY USA p 71-75 AMEIEW
Abstract: The dynamic behaviour of the reed valves for the two-cycle engine, due to the conditions of unsteady flow regime, was one of the few remaining aspects of two-cycle engine operation which, until recent times, has received relatively little research. This paper deals with the theoretical model for the reed valve dynamics. The mathematical representation of the reed valve behaviour follows the previous works from Hinds and Blair. Some previous models analyze only the deflection of the free end of the reed. This type of model is not adequate for the correct characterization of valve dynamics which is pretended, because in this way it is not possible to know in which intermediate position could take contact the reed with the seat or the stop plate. So, the representation of the reed dynamics must calculate the shape of the whole reed as it lifts off the valve seat. The model, which is presented, has been implemented in a global code for the calculation of the operation of the engine, developed by the same research group, and it is applied to the characterization of a racing two-stroke engine with reed valve, the 1993 HONDA RS125R. The results of the calculation are quite satisfactory, as it can be concluded from the comparison with the experimental data presented. **English** (Author abstract) 5 Refs.

Exhaust emission control through catalytic activation of the combustion in a two-stroke SI engine
Author(s): Babu, P.R.; Cherian, N.K.; Nagalingam, B.; Gopalakrishnan, K.V.
Author Affiliation: Indian Inst of Technology
Source: International Conference on Environmental Pollution Proceedings of International Conference on Environmental Pollution - ICEP-1 Apr 1991 1991 Pub by Inderscience Enterprises Ltd Geneva Aeroport 15 Switz p 195-203
Abstract: There is a great need for finding an effective solution to the growing problem of environmental pollution from gasoline-powered SI engines of the present day. Use of catalysts in the combustion chamber can be a way to improve the combustion process by increased chemical activity of the charge prior to ignition. This paper discusses the performance, combustion and emission characteristics of a two-stroke spark ignition engine in which the combustion is made to occur in a catalytically activated combustion chamber. Catalysts such as copper, chromium and nickel in the form of coating and a catalytic prechamber with platinum tipped multi-electrode spark plug were tried out to ensure rapid and efficient combustion. Considerable reduction of CO and HC emissions were obtained with some of the catalysts. **English** (Author abstract) 4 Refs

Effective utilization and reduction of emissions of the exhaust gas in a two-stroke-cycle engine
Author(s): Sato, Kazuo; Ogawa, Youichirou; Nakano, Masamitsu
Author Affiliation:
Source: Nippon Kikai Gakkai Ronbunshu, B Hen/Transactions of the Japan Society of Mechanical Engineers, Part B v 57 n 534 Feb 1991 p 756-761 0387-5016 NKGBDD
Abstract: This paper deals with a successful attempt to employ the exhaust gas of a two-stroke-cycle gasoline engine as an energy source to burn a burner and heat a Stirling engine, and to clean the exhaust gas by a catalyzer. By means of a rotary valve and the exhaust pipe sections, the exhaust could be separated into a high concentration of fresh gas and a high concentration of combustion gas. The former gas was burned by a burner, and then used to heat a Stirling engine. The latter gas was disposed of by an oxidization catalyzer. The investigation revealed the enthalpy and exergy flows of a two-stroke-cycle gasoline engine, a burner, a catalyzer and a Stirling engine, and then the emission gases (HC, CO) were disposed of by the burner and catalyzer. The investigative analysis shows a method of successfully transferring the energy available in the exhaust gas for the combustion of a burner and the operation of a Stirling engine, and the near perfect elimination of the emission gases in the exhaust gas by a burner and a catalyzer. **Japanese** (Author abstract) 11 Refs

Search for quantum leap in cylinder oils
Author(s): Anon
Author Affiliation:
Source: Marine Engineers Review Jan 1995 Marine Management (Holdings) Ltd London Engl p 36 0047-5955 MRERBJ
Abstract: In the global marine lubricants markets, Mobile claims a leading position with about 22% of the international share. The oil company intends to maintain and increase this share by demonstrating its commitment to research and by promoting the benefits of its expertise. With the a six-cylinder Sulter RTA38 two-stroke engine, Mobil is conducting a broad range of tests in its search for the future's cylinder lubricants and from which it hopes to achieve a 'quantum leap' in cylinder oil technology. **English**

Measurement and reduction of particles emitted from a two-stroke engine
Author(s): Patschull, J.; Roth, P.
Author Affiliation: Universitaet Duisburg

Source: Journal of Aerosol Science Proceedings of the 1994 European Aerosol Conference May 30-Jun 2 1994 v 25 n SUPPL 1 May 1994 Blois, Fr, Sponsored by: G.A.M.S./COFERA; Gesellschaft fur Aerosolforschung (GAeF) Pub by Pergamon Press Inc Tarrytown NY USA p 323-324 0021-8502 JALSB7

Abstract: The paper reports on measurements of exhaust gas particles emitted by a two-stroke engine. After aerosol sampling and dilution, particle size classification was performed by using a Differential Mobility Particle Sizer (DPMS). Results indicated that neither mineral nor synthetic lubrication oil had any influence on the emission characteristics. **English** 4.

Effect of gasoline and lubricant on emissions and mutagenicity of particles and semivolatiles in chain saw exhaust

Author(s): Magnusson, Roger; Nilsson, Calle; Andersson, Kurt; Andersson, Barbro; Rannug, Ulf; Ostman, Conny

Author Affiliation: Swedish Univ of Agricultural Sciences

Source: Environmental Science and Technology v34 n14 Jul 2000 ACS Washington DC USA p 2918-2924 0013-936X ESTHAG

Abstract: The exhaust from a two-stroke chain saw engine was characterized using two different types of gasoline, aliphatic gasoline and conventional lead-free gasoline, in combination with four lubricants differing in mineral oil, polyolester, and polyisobutylene (PIB) content. This characterization was focused on emissions of polycyclic aromatic hydrocarbons (PAH) and mutagenicity testing using Ames Salmonella assay. In addition, exhaust emissions of carbon monoxide (CO), nitrogen oxides (NOx), aldehydes, and hydrocarbons (HC) were measured. The two-stroke engine was tested in a test bench, and particulate, semivolatile, and gaseous exhaust components were sampled using a dilution tunnel. Much less PAH were emitted when using aliphatic gasoline due to a much lower gasoline content of PAH and aromatics than the conventional gasoline. Also about half the NOx emissions, up to 50% higher formaldehyde and acetaldehyde emissions, and 10% higher total HC emissions were observed for the aliphatic gasoline. The influence of lubricant on the studied exhaust emissions was found to be of minor importance. In terms of mutagenicity, significant effects were seen for six of the eight gasoline/lubricant combinations, and the highest effects were observed without a metabolizing system. Generally, the conventional gasoline gave higher effects than did the aliphatic gasoline. A difference between lubricants was also seen, especially in combination with gasoline A; however, the interpretation of mutagenic effects of the lubricants was not straightforward. Overall, one synthetic ester-based lubricant and one

mineral oil-based lubricant gave the highest mutagenicity. **English** (Author abstract) 27 Refs.

Volatility of exhaust particles emitted from a two-stroke engine
Author(s): Alander, T.; Antikainen, E.; Raunemaa, T.; Elonen, E.; Ahokas, J.; Rautiola, A.
Author Affiliation: Univ of Kuopio
Source: Journal of Aerosol Science The 2000 European Aerosol Conference Aug 3-Sep 8 2000 v31 nSUPPL. 1 Sep 2000 Dublin, Ireland, Elsevier Science Ltd Exeter Engl p S877-S878 0021-8502 JALSB7
Abstract: The volatility of particles emitted from a 50 cm3 two-stroke engine with 2.5 kW rated power output was investigated. The two oil/fuel mixtures applied to test were a biodegradable lubrication oil with special small engine gasoline containing no aromatics and a conventional but partially synthetic lubrication oil with standard gasoline. Scanning mobility particle sizers (SMPS) were used for the measurement for the particle size distributions. The evaporation of total particle volume agreed with the thermal-optical carbon analysis. **English** 2 Refs.

Spectrophotometry of fine aerosols emitted by internal combustion engines
Author(s): Borghese, A.
Author Affiliation: Istituto Motori - CNR
Source: Journal of Aerosol Science The 2000 European Aerosol Conference Aug 3-Sep 8 2000 v31 nSUPPL. 1 Sep 2000 Dublin, Ireland, Elsevier Science Ltd Exeter Engl p S626-S627 0021-8502 JALSB7
Abstract: An analysis of the optical properties of the exhausts of internal combustion engines (ICE) is presented. The open-path spectrophotometry was used to optically analyze the air-diluted exhaust emissions of the vehicles. The extinction spectra of air-diluted emissions of ICE show structureless broad continua which give information on physical and chemical properties of the particulate matter. The interpretation results of intensity and shapes of the extinction spectra and their relationship with different classes of particles like carbon black, fine and transparent particles present in the exhaust of two-stroke engines, and organic matter are presented. **English** 3 Refs.

END NOTES

[i] John B. Heywood & Eran Sher, **The Two-Stroke Cycle Engine**, Taylor & Francis (SAE), 1999.

[ii] John P. Norbye, **The Wankel Engine**, Chilton Book Company, Philadelphia, 1971.

[iii] **Emissions from in-use lawn-mowers in Australia**
Author(s): Priest, M.W.; Williams, D.J.; Bridgman, H.A.
Author Affiliation: Univ of Newcastle
Source: Atmospheric Environment v34 n4 2000 Elsevier Science Ltd Exeter Engl p 657-664 1352-2310 ATENBP
Abstract: Concern over the levels of pollutants emitted from small engines has led to recent legislation in the United States that regulates exhaust emissions from lawn and garden equipment. Particular attention has focused on the high levels of hydrocarbons emitted by these engines. The present study establishes emission factors for lawn mowers in use in Australia. The estimates were calculated on the basis of a series of controlled emission tests conducted on commonly used lawn mowers. Ten two-stroke and six four-stroke lawn-mower engines were operated under simulated power requirements while fuel usage and gas emissions were monitored. Fuel consumption rates from the tests were compared to those ascertained under actual mowing conditions in field tests conducted on 19 two-stroke and ten four-stroke lawn mowers. Basic emission factors were established for CO, CO2, CH4, NMHC and Knox, and combined with data on machine population and annual usage collected in a survey of lawn care practices and lawn-mower usage conducted in the Newcastle area. When compared to transport sources in the Newcastle study region, lawn mowers contribute 5.2 and 11.6% of CO and NMHC emissions, respectively.
English (Author abstract) 12 Refs.

[iv] Associated Press, April 13, 2001, taken from *Seattle Post-Intelligencer.*

[v] Quote from Monita Fontaine, Director of Personal Watercraft Industry Association, AP, April 13, 2001.

[vi] Abstract: A multicylinder, two-stroke, radial, internal combustion engine employs a multi-blade positive-displacement pump for pressurizing a mixture of air/fuel/lubricant supplied to a plurality of cooperating cylinders. One of the pistons is connected to a master connecting rod, which bears a

plurality of crank pins respectively connected to the connecting rods of the other piston/cylinder assemblies of the multicylinder engine. The exhaust gases from the plurality of cooperating cylinders are collected in a common annular exhaust manifold and quietly emitted therefrom through a single exhaust port in a downward direction. A multibladed, positive-displacement pump draws an air/fuel/lubricant mixture from a carburetor through an annular volute, which promotes fuel evaporation and supplies a pressurized intake flow to the cylinders via a single shared crankcase.

[vii] Abstract: The present invention relates to operation processes of two-stroke engines. A two-stroke engine uses a slide valve (10) so that the inlet-outlet passage (9) connected to the exhaust manifold (18) may be connected to the inlet pipe after the outlet of exhaust gases from the cylinder (4). A fresh load is then introduced into the cylinder (4) simultaneously through a scavenging port (6) connected to the crankshaft chamber (2) by a scavenging passage, and through an inlet-outlet port (8) connected to the inlet pipe. The crankshaft chamber (2) is filled when the piston (5) moves from the bottom dead center after the port (8) is opened at its lower edge. Practically continuous feeding of fresh loads into a single-cylinder engine can thus be achieved. The increase in the time-section ration of the gas distribution organs ensures maximum filling of the cylinder (4) while reducing the time therefor and the losses to a minimum. The heat, which is emitted at the surface of the hottest parts after the outlet, is instantaneously eliminated by the cold fresh loads passing there through.

[viii] Abstract: A two-stroke internal combustion engine having a compressed air assisted fuel injection system. The injection system has an accumulator that uses scavenged air from the crankcase as the compressed air source. The injection system has a valve connected to an exit from the accumulator. The valve is connected to a diaphragm with two diaphragm pressure chambers on opposite sides of the diaphragm. Both diaphragm pressure chambers are connected to pressure in the crankcase; one of the diaphragm pressure chambers by a flow restrictor.

[ix] Abstract: The present invention is to provide an electronically controlled fuel injection type two-stroke engine wherein the intake air amount can be determined with precision so that the fuel injection amount can be properly controlled in conformity with the varying conditions of the exhaust pressure, to thereby achieve an optimal air-fuel ratio and hence improve the output power, the fuel consumption and the exhaust performance. For the computation of the correction value to the fuel injection amount based on the intake passage pressure, the actual throttle opening and engine speed

are detected, and the intake pressure value P is detected at the same time. Then the corresponding basic intake pressure value is selected from the basic intake pressure map so as to calculate the difference between the basic intake pressure value and the detected intake pressure value. This difference corresponds to the difference in exhaust pressure between the base state and the actual run state (exhaust pressure varies depending upon the conditions such as the boat speed, forward/backward mode, the mounted position (height) and the number of the mounted engines and the like). From this difference, the correction value to the fuel injection amount based on the intake pressure is computed.

[x] Abstract: A two-cycle internal combustion engine implements low-pressure, cylinder wall fuel injection and uses a notched exhaust port or the like to control cylinder pressure rise during exhaust port closure. An electronic control unit controls the operation of fuel injection through the cylinder wall. Fuel injection terminates before the piston closes the exhaust port as the piston travels from bottom dead center to top dead center. The exhaust port notch tempers pressure gradients and pressure fluctuations in the piston cavity that can otherwise occur before the exhaust port closes and can be detrimental to the control of low-pressure fuel injectors. The exhaust port notch allows better fuel injection control, especially at idle or low speeds, without requiring the port positions and configurations to be modified which could compromise engine performance at medium or high speeds.

[xi] Abstract: A crankcase scavenged two-stroke engine includes a piston reciprocally mounted in a cylinder. The cylinder wall has an exhaust port and a rear transfer port opposed thereto formed in it. The rear transfer port communicates with the interior of the crankcase via a rear transfer passage and is arranged to open before the exhaust port closes, whereby, in use, the cylinder is scavenged. An inlet duct is arranged to supply combustion air to the crankcase and a throttling valve is arranged to throttle the flow of air through the inlet duct. A carburetor is arranged to supply fuel into the inlet duct. The interior of the crankcase is divided into at least two separate crankcase volumes, a rich volume (V1,V2) and a lean volume (V3). Each crankcase volume communicates with the cylinder via a respective hole in the crankcase wall. The cylinder wall also has at least one lateral transfer port formed in it at a position between the rear transfer port and the exhaust port. The lateral transfer port is arranged to open before the exhaust port closes. The lateral transfer port communicates with the lean volume (V3) via a lateral transfer passage. The rear transfer port communicates with the rich volume (V1,V2). The inlet duct is divided over

at least part of its length into at least two inlet passages, a rich passage and a lean passage, which communicate with the rich volume (V1,V2) and the lean volume (V3), respectively. The carburetor and/or the throttle valve are so constructed and arranged that, under high load operation, substantially all the fuel supplied by the carburetor is introduced into the rich passage and, under low load operation, the fuel supplied by the carburetor is introduced into both the rich and lean passages.

[xii] Abstract: In order to provide a mixture-compressing two-stroke Otto engine with fuel injection into the cylinder space, in which it is in particular intended to make a homogeneous mixture formation possible, it is proposed that the combustion space (19) possesses essentially the configuration of a hemisphere and, with its combustion space axis (21), is, from the cylinder axis (20) relative to the side of the cylinder (11) located opposite the exhaust duct (14), disposed so as to be offset, the injection nozzle being disposed relative to the combustion space (19 in such a way that the upper portion of the jet cone (22) penetrates a predominant volume proportion of the combustion space (19), while the lower portion of the jet cone extends underneath the cylinder bottom plane (25) approximately obliquely to the cylinder axis (20), but outside the combustion space (19).

[xiii] Abstract: An improved two stroke, reciprocating, internal combustion engine, with multiple cylinders, each closed by a cylinder head and containing a power piston which is connected to a power output shaft. Each cylinder has means for the intake of working fluid and a cooler for the compressed air. It also contains a displacer that moves between the cylinder head and the power piston. This displacer contains one way flow valving, a means for the exhausting of the working fluid from the cylinder, a movable alternating flow heat exchanger used as a regenerator, a heat shield, and a means to bypass the regenerator. The linkage from the power output shaft to move the displacer contains a spring and damper arrangement that allows the compression and expansion ratios to be varied.

[xiv] Abstract: The present invention pertains to the field of engine construction and relates to internal combustion engines with scavenging and more precisely to two-stroke engines. At the beginning of the exhaust stroke, the exhaust gases are expelled from the engine cylinder through inlet and outlet ports, inlet and outlet passages and slide valves into an exhaust pipe. Scavenging ports are then uncovered by an upper edge of the piston and used to feed a fresh charge into the cylinder from the crank chamber while the cylinder cavity is scavenged. After expelling the exhaust

gases from the cylinder cavity, the slide valves rotate to interrupt the communication between the cylinder cavity and exhaust manifold. Upon further rotation of the slide valves, the cylinder cavity is connected with the inlet pipe through the same gas-distribution organs used for the exhaust gas outlet, i.e. the inlet and outlet ports, the inlet and outlet passages and the slide valves. A fresh charge can thus be fed into the cylinder through all the ports it comprises, whereby the cylinder of a two-strike engine may be charged without any losses in the charges and with the appropriate preliminary compression ratio.

[xv] Abstract: An internal combustion powered tool, such as a nail or fastener driver, and a control system, spark source, and rotary valve for use in an internal combustion powered tool are disclosed. The tool may include, for example, a cylinder and a piston reciprocally moveable within the cylinder. A combustion chamber is defined at one end of the cylinder, with the piston comprising a portion of one end of the combustion chamber. The tool may have a fastener driver associated with the piston, and a magazine for feeding fasteners into registration with the driver. A fuel flow passageway extends between a fuel source and the combustion chamber, and a metering valve controls the flow of fuel to the combustion chamber. A spark source within the combustion chamber is provided for igniting the fuel, and an intake and exhaust valve that includes a pair of diametrically opposed apertures is provided. At least one fan external to the combustion chamber induces an intake of fresh air into the combustion chamber through one of the apertures and an exhaust of combustion products from the combustion chamber through the other aperture. Additional and alternative details and features are described in the disclosure.

[xvi] Abstract: An exhaust pipe for an internal combustion engine has non-circular passages that extend from the engine exhaust port to the atmosphere. The performance of the engine is not impaired by the non-circular passages compared with prior pipes having circular passages of the same cross sectional areas at corresponding locations along the pipes. The non-circular cross section enables two or more passages to be located inside a single outer wall. Plates inside the outer wall divide the outer wall interior into the separate passages. Adjacent passages thus share a wall. The exhaust pipe includes headers that conduct exhaust gasses directly from the engine to the associated passages. In a modification of the invention, an exhaust pipe is tuned for performance at two different engine-operating speeds by tuning a passage on one side of a shared wall differently than another passage on the other side of a shared wall.

[xvii] Abstract: An engine control scheme determines the appropriate and desired magnitude of scavenging air flow for a two stroke engine as a function of both load and engine speed. The desired airflow is determined, as a function of engine load and engine speed, to achieve an optimal magnitude of emissions within the exhaust stream and to also optimize a reverse thrust capabilities of the marine propulsion system.

[xviii] Abstract: A two-stroke internal combustion engine is disclosed having opposed cylinders, each cylinder having a pair of opposed pistons, with all the pistons connected to a common central crankshaft. The inboard pistons of each cylinder are connected to the crankshaft with pushrods and the outboard pistons are connected to the crankshaft with pull rods. This configuration results in a compact engine with a very low profile, in which the free mass forces can be essentially totally balanced. The engine configuration also allows for asymmetrical timing of the intake and exhaust ports through independent angular positioning of the eccentrics on the crankshaft, making the engine suitable for supercharging.

[xix] Abstract: A two-stroke cycle engine having an improvement of its power output while reducing total hydrocarbons in the exhaust gases. The two-stroke cycle engine comprises a crank chamber adapted to receive a fuel mixture through feed means and a combustion chamber in a cylinder. Scavenging ports are provided for communication between the combustion chamber and the crank chamber to transfer the fuel mixture from the crank chamber to the combustion chamber while an exhaust port is provided for exhausting the burned gases from the combustion chamber. Reciprocation of the piston results in increase or decrease in volume of the combustion chamber while opening or closing the exhaust port and the scavenging ports. Communication means are provided for communicating the exhaust port with the crank chamber via the scavenging ports to draw a portion of the burned gases from the exhaust port into the crank chamber when the piston is in its top dead center.

[xx] Abstract: A two stroke cycle reciprocating piston internal combustion engine having horizontally opposed cylinders and pistons, scotch yokes and self adjusting sliding blocks for the interface between the scotch yokes and crankpins, and secondary cylindrical pistons to maintain the scotch yokes in perpendicular vertical alignment with the crankpins. The secondary cylindrical pistons also operate as valves to open exhaust ports. A supercharger forces air through intake ports and into the main cylinders, then into secondary cylinders, and scavenges the exhaust gases through the exhaust ports. There is no carburetor and no adjustable distributor but

rather ignition signals within its operating range, at a certain angle before top dead center. In addition, a capacitive discharge ignition system using multiple transformer ignition coils for each cylinder and rail spark plugs with multiple sets of rails to ignite very lean air/fuel mixtures. And lastly, a capacitive discharge system with rail fuel injectors, to supply the required amount of fuel into each cylinder at the proper time.

[xxi] Abstract: A loop-scavenged two-stroke internal combustion engines with an intake valve (7) engaging a seat (10) for fresh air intake, and an exhaust valve (8) engaging a seat (13) for combustion gas exhaust, is disclosed. The valves are arranged in such a way that the fresh air intake scavenges a substantial part of the burnt gases. In at least one of the valves, the valve surface (21) located downstream from the valve face (9) and the surface (23) of the downstream extension of the seat (10) are configured in such a way that they form a substantially isentropic diffuser.

[xxii] Abstract: Ester base stocks for two-cycle gasoline engine lubricant compositions are disclosed which produce lower amounts of observable smoke in the exhaust emitted as a result of combustion in a two-cycle gasoline engine, require no miscibility-enhancing solvents, have a viscosity of 3.0 cSt to 20.0 cSt at 100° C. and a smoke index of at least 75. Some of the esters are biodegradable.

[xxiii] John Zabsky, KleenAir Systems, Inc. 828 Production Place, Newport Beach, CA 92663, (949) 574-1600. This company offers carburetor technology, but has so far emphasized four-stroke work. It could, with funding, extend attention to two-stroke engines and applications.

[xxiv] Abstract. A combustible mixture of air and minute fuel droplets is produced for supply to the cylinders of an internal combustion engine. This mixture is formed by accurately controlling both the atomization of fuel and the mass flow rate of air over substantially the entire operating range of the engine. These controls are accomplished by introducing liquid fuel into a stream of intake air and uniformly distributing the fuel in the air followed by passing the air and fuel mixture through a constricted zone to increase the velocity of the mixture to sonic. The sonic velocity air at the constricted zone divides the fuel into minute droplets that are uniformly entrained throughout the air stream. The area of the constricted zone and the quantity of fuel introduced are adjustably varied in correlation with operating demands imposed upon the engine. Downstream from the constricted sonic zone, the air and fuel mixture is accelerated to supersonic velocity in a supersonic zone without imparting substantial turbulent flow

thereto. Thereafter the mixture is decelerated to subsonic velocity in a subsonic zone to produce a shock zone where the fuel droplets entrained in the air are believed to be further subdivided and uniformly distributed throughout the combustible mixture before the mixture is supplied to the engine cylinders. The supersonic and subsonic velocities occur in a gradually increasing cross-sectional area corresponding to that of a conical section having an apex angle in the range of about 6° to 18°. Operation of the engine with such a combustible mixture results in substantially reduced levels of undesirable exhaust emissions, and also permits operation of high compression ratio engines on relatively low octane fuel with good power and fuel economy characteristics. Additionally, misfire does not occur even when the engine is operated on relatively lean air-fuel ratios.

[xxv] Blank spaces in Assignee column mean that patents are not assigned to companies, usually meaning that the individual inventor(s) hold rights. Reassignment of rights or licenses granted to companies is not available in the database.

[xxvi] Blank cell in this column indicates the patent is unassigned at time of issue.

[xxvii] William Edmonston, Atomized Fuel Technologies, Inc., 13465 Nomwaket Road, Apple Valley, CA 92308. (750) 240-5903.

[xxviii] AP byline, dated Friday, April 13, from *Seattle Post-Intelligencer*.

[xxix] This portion of the table, with blank spaces in the Assignee column, indicates the patents were not assigned to a company on issuance. Information on subsequent licenses or assignment is not available in the databases used in this research.